Exit Strategies from Quantitative Easing: The role of the fiscal-monetary policy mix*

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Abstract

As a consequence of the policy responses to the COVID-19 crisis, central bank balance sheets, public debt and liquidity increased in many developed economies. As the economies recover and inflation far exceeds the target, central banks face a challenge in how to manage their balance sheet. I study the macroeconomic effects of reducing the central bank balance sheet size, i.e., Quantitative Tightening (QT). I construct a Regime-Switching New Keynesian DSGE model calibrated to the US economy before the COVID-19 crisis. The economy fluctuates between a monetary-led regime, a fiscally-led regime, and the zero lower bound on the monetary policy interest rate. The macroeconomic effects of QT crucially depend on the fiscal-monetary policy mix. In a monetary-led regime, QT reduces inflation at the cost of increasing the government debt-to-GDP ratio. The effects on output, inflation, and debt depend on the strategy's aggressiveness. In contrast, unwinding the central bank balance sheet in a fiscally-led regime has little impact on inflation. The negative demand effect driven by QT is not enough to counteract the stimulative impact of negative real interest rates and fiscal stimulus.

Keywords: Monetary Policy; Fiscal and monetary policy mix; Quantitative Easing; Quantitative Tightening

JEL Classification: E31, E52, E58, E62, E63

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"...I would just stress how uncertain the effect is of shrinking the balance sheet..."

J. Powell, Federal Reserve Chairman, press conference May 2022.

1 Introduction

During the great recession and the COVID-19 crisis, short-term interest rates in the US approached the zero lower bound (ZLB), leaving the Federal Reserve without its conventional monetary policy instrument. As a result, the Federal Reserve (like many other central banks) expanded its balance sheet to stimulate the economy through lower interest rates of longer horizons. The expansion of the central bank balance sheet through the purchase of large amounts of assets with the objective to stimulate output and inflation is known as Quantitative Easing (QE).[1][2] The counterpart of this expansion on the asset' side is an increase in the central bank liabilities, mainly in the form of bank reserves and currency in circulation. At the same time, there was a massive fiscal expansion in the form of larger fiscal deficits and debt-to-GDP ratios not seen since World War II.

As the economy recovers and the inflation rate reaches values not seen for forty years, the Federal Reserve (and other central banks) face the challenge of removing the economic stimulus introduced during the crisis. In particular, there is significant uncertainty regarding the macroeconomic effects of unwinding the central bank balance sheet. In this paper, I shed light into that question. This paper quantifies the effects of reducing the central bank balance sheet size on macroeconomic and financial variables like inflation, government debt, and yield spreads.

I construct a Regime-Switching New Keynesian Dynamic Stochastic General Equilibrium (NK-DSGE) model calibrated to the US economy before the COVID-19 crisis. The model has five agents: households, financial intermediaries, firms, the central bank, and the fiscal

[1] In practice, QE includes distinct policies. In this paper, QE consists of central bank purchases of long-term public bonds by selling short-term assets (bank reserves). The main objective of this policy is to stimulate output and inflation by lowering long-term yields. This policy was defined as QE-type 2 by Ricardo Reis in his talk "The original sin of QE."

[2] As the empirical literature on quantitative easing macroeconomic effects has shown, these policies have a substantial impact on long-term interest rates, output, and inflation. See, for instance: Vissing-Jorgensen (2021) for effects on yields, Bhattarai and Neely (Forthcoming), for a review of macroeconomic effects of these policies.

authority. The fiscal authority issues long and short-term bonds, while the central bank issues reserves. The central bank does conventional monetary policy, which consists in setting the short-term interest rate, and unconventional monetary policy: Quantitative Easing. QE consists of central bank purchases of long-term government bonds from households, paid by issuing reserves to financial intermediaries.[3] The model exhibits market segmentation in the public debt market and a leverage constraint for financial intermediaries, as in Elenev et al. (2021). Due to these frictions, Quantitative Easing policies generate portfolio rebalancing effects for households and financial intermediaries, causing real effects.

Conventional monetary and fiscal policies consist of a Taylor rule for the short-term interest rate (the return on short-term public bonds and reserves) and a fiscal rule for taxes. The parameters in these rules switch between three policy regimes, as in Bianchi and Melosi (2017) and Bianchi and Melosi (2022): a monetary-led regime, a fiscal-led regime, and a Zero Lower Bound regime. In the first regime, the central bank reacts strongly to inflation deviations from the target, and the fiscal authority adjusts the primary fiscal surplus to stabilize the public debt. This behaviour was characterized as *active* monetary policy and *passive* fiscal policy in Leeper (1991) and the following literature. In the second regime, the fiscal authority does not adjust the fiscal surplus enough to stabilize the debt. As a result, the monetary authority allows the inflation rate to deviate from the target to stabilize debt in real terms (*active* fiscal policy and *passive* monetary policy). Finally, the ZLB regime represents a crisis regime, where the monetary authority is left with no room to stimulate the economy by decreasing the short-term nominal interest rate since it reached its effective lower bound. The fiscal authority stimulates the economy by not reacting to debt deviations. This last regime constitutes an extreme version of the fiscally-led regime. The economy presents recurrent regime switches following a transition matrix. Differently from Bianchi and Melosi (2017), the transition to and from the ZLB regime is endogenous.

[3] In practice, if households are the original owners of the bonds purchased by the central bank, the mechanism is as follows. First, households sell the bond to their financial intermediary, which pays through deposits. Then, the financial institution sells the bond to the central bank, which increases the bank reserves. The model generates the same increment in macroeconomic aggregates while abstracting from the intermediate transaction.

The probability of entering the ZLB regime decreases with the nominal interest rate; and it is equal to one when the net interest rate is below or very close to zero.[4] The likelihood of exiting the ZLB is increasing in a shadow interest rate. The shadow interest rate is equal to the Taylor Rule that the central bank would have followed in the monetary-led regime, without the lower bound. The endogeneity surrounding this regime allows the agents in the economy to form rational expectations toward the occurrence of this regime based on their information on macroeconomic variables like inflation, output, and nominal interest rates. The endogenization of this transition probability constitutes one of the contributions of this paper.

The QE transmission mechanism operates through two channels in this model. First, when the central bank introduces reserves in the intermediary sector, it relaxes the leverage constraint for financial intermediaries, allowing them to increase the deposit supply to households. Second, the central bank intervention in the long-term bond market drives up the bond price, and the long-term yield falls. This price increase gives families incentives to rebalance their portfolio, selling their long-term bonds and exchanging them for deposits. QE transmits into the economy as a demand shock. The portfolio revaluation effect provides households with a wealth effect, increasing consumption. The fall in savings return generates a substitution effect from savings to consumption. Both channels operate increasing aggregate demand in this economy. This ultimately raises inflation, consumption, and output.

The main contribution of this paper is showing that the impact of central bank balance sheet policies depends on the fiscal-monetary policy mix. Even though asset purchase programs are typically studied as a purely monetary problem, this paper shows that the interaction between the fiscal and monetary authorities is critical during these programs. First, QE reduces public debt issuance. The central bank intervention increases the long-term debt price, depressing the interest rate payments the government has to pay and increasing the central bank's profits, which are transferred to the Treasury. On top of this, QE fosters a

[4]As explained in section 4, the probability of being at the ZLB at period $t+1$ depends on the interest rate at period t. This implies that if the economy receives a strong negative shock that drives the inflation rate and (or) the output below their targets at period t, there may be draws of the shocks for which the net interest rate is below zero before moving to the ZLB regime. The frequency of these cases is minimized through calibration.

faster recovery, reducing the primary fiscal deficit. All these factors allow the treasury to decrease the debt-to-GDP ratio. Second, as a counterpart of the central bank's balance sheet expansions, liquidity increases substantially, both in the hand of commercial banks (reserves) and households (deposits). The extent to which the increase in liquidity affects output and inflation rate depends on the fiscal-monetary policy mix.

At the ZLB regime, the fixed short-term interest rate exacerbates the substitution effect between savings and consumption. The short-term nominal interest rate increases in the fiscal and monetary-led regimes, following the corresponding Taylor rule. This interest rate increase ameliorates the expansionary and inflationary effects of an increase in central bank purchases, especially in the monetary-led regime where the real short-term interest rate becomes positive.

How the central bank balance sheet's size is reduced matters for inflation, output, and debt dynamics. I simulate a crisis that resembles the one derived from the COVID-19 pandemic and the policy response. In the crisis recovery, I study different strategies regarding the size of the central bank balance sheet: 1) maintaining the enlarged size after the crisis (*tapering*), 2) decreasing the balance sheet size: a) by letting the bonds that mature, run off the balance sheet (*Quantitative Tightening (QT)*), and b) at a faster speed by selling bonds (*Aggressive QT*).

Unwinding the central bank balance sheet contributes to inflation stabilization in the average simulation across samples and regimes, i.e., where the economy is in the monetary or the fiscally-led regime with positive probability. When the central bank reduces its purchases of long-term public bonds, it triggers a price fall and an increase in long-term yields. This ultimately reduces aggregate demand, mainly through a negative wealth effect. Output and inflation decrease; thus, the short-term interest rate is lower than in a situation without balance sheet reduction. However, it comes at the cost of a higher debt-to-GDP ratio driven by the rise of the primary fiscal deficit and debt service. These effects are more substantial when the QT policy is more aggressive.

In a fiscally-led regime, however, there are no clear advantages in reducing the balance sheet size. The negative demand shock generated by QT is unable to counteract the stimulative effect of real negative interest rates and fiscal deficits. As a result, unwinding the central bank balance sheet increases debt and spreads without helping reduce inflation back to target.

This paper contributes to several strands of the literature. In particular, it contributes to the literature that studies the real and inflationary effects of QE through different channels. As summarized by Bhattarai and Neely (Forthcoming) and Kuttner (2018), the literature has emphasized distinct channels through which these policies can affect variables like output and inflation. In particular, portfolio rebalancing effects, signaling channels of future interest rates, liquidity effects, among others. A crucial missing piece in these papers is the role of fiscal policy. To isolate the effect of monetary policies, the literature typically simplifies fiscal authority behavior. It assumes the fiscal authority adjusts taxes to satisfy the government budget constraint at all periods, leaving the role of inflation stabilization to the central bank. However, under these assumptions, there is no role for policy uncertainty, and inflationary surprises to stabilize debt are ruled out. This paper fills that gap by allowing the fiscal-monetary policy mix to play a role in shaping the macroeconomic effects of unconventional policies and showing alternative scenarios where fiscal and monetary policy interact.

Elenev et al. (2021) ask whether monetary policy can create fiscal capacity. In their setting, fiscal capacity depends on the probability of shifting fiscal policy from active to passive. In this sense, I share with them the objective of studying the effects of unconventional monetary policies while allowing fiscal policy to shift between regimes. The main difference with this paper is that Elenev et al. (2021) assume and estimate a fiscal limit beyond which the Treasury starts increasing taxes to ensure debt sustainability. At the same time, the conventional monetary policy is active at all periods. These assumptions prevent inflationary dynamics from arising in the model since all the agents in the economy are rational and know the government will never inflate away part of the debt. My main contribution here is to study exit strategies from Quantitative Easing programs when fiscal and monetary authorities can follow a different policy configuration.

Many authors studied the transmission mechanisms of Quantitative Easing programs in general equilibrium models, either with financial frictions, like in Gertler and Karadi (2011), Sims and Wu (2021), Sims et al. (2020), Del Negro et al. (2017), among others; or with market segmentation and/or portfolio adjustment costs as the main mechanisms to break the non-arbitrage condition between short-term and long-term bonds, as in Chen et al. (2012), Harrison (2017). Furthermore, a recent paper by Cui and Sterk (2021) studies the liquidity effects of asset purchase programs in a model with heterogeneous agents. The main contribution to this strand of the literature is providing richer modeling of the fiscal sector and allowing recurrent policy regime switches in the context of a Dynamic Stochastic General Equilibrium (DSGE) model.

By giving a central role to the interaction or coordination of fiscal and monetary policies, this paper also relates to the literature that studies fiscal-monetary policy mix, typically in normal times and as simple rules, as in Leeper (1991), Schmitt-Grohé and Uribe (2007), Leeper and Leith (2016), and to the literature of the Fiscal Theory of the Price Level as in Cochrane (2001), Cochrane (2021). Allowing the policy mix to change among regimes, this paper also relates to the literature on regime switches in policy rules, as in Bianchi (2013), Bianchi and Melosi (2017), Bianchi and Melosi (2022), among others. The contribution to this branch of the literature is the study of unconventional monetary policies together with the conventional Taylor rule on short-term interest rates.

This paper focuses on the macroeconomic effects of reducing the central bank balance sheet. In a broad sense, I share the question with Wen et al. (2014), Harrison (2017), Sims et al. (2020), Bonciani and Oh (2021). However, this paper differs from these in many aspects. Wen et al. (2014) studies the exit strategy from QE programs emphasizing the importance of the timing and the pace of the exit, and the private sector expectations of the exit, as I do, but their focus relies on the impact on firms, while there is no role for the fiscal authority. Harrison (2017) studies the optimal QE policy in a DSGE-NK model with portfolio adjustment cost, and Sims et al. (2020) studies optimal simple and implementable QE rules through minimizing a quadratic loss-function in a DSGE-NK model with financial frictions. Bonciani and Oh (2021) extends the work of Sims et al. (2020) by showing that the central bank's loss function depends on the central bank's asset purchases volatility. Crucial differences are that these articles focus on central bank purchases of corporate/ private sector bonds, assume a limited role in fiscal policy, and do not allow for changes in the conduct of the fiscal policy rule. Foerster (2015) studies the macroeconomic effects of unwinding the central bank balance sheet during and after a financial crisis. He shows that private agents' expectations about the exit strategy from a QE program impact the initial effectiveness of the policy in a MS-DSGE model with a financial sector. However, there is no role for parameter switches in conventional policy rules, abstracting from the possibility of alternative fiscal-monetary policy interactions, which is the main contribution of this paper.

In a recent related paper, Benigno and Benigno (2022) study monetary policy normalization, defined as the combination of lifting the policy rate and reducing the size of Central Bank balance sheets. We share the research question and the interest in studying how these monetary policies interact and how they depend on the behavior of the fiscal authority. However, we have substantial differences. Their focus relies on optimal policy analysis and does not account for policy uncertainty in the configuration of fiscal and monetary policy interactions, which constitutes a central contribution of this paper.

The remainder of the paper goes as follows. In the following section, I provide motivating evidence of the importance of the fiscal and monetary policies interaction during Quantitative Easing programs, looking at data for the US during the COVID-19 crisis. Section 3 presents the model, section 4 discusses the calibration, functional forms, and solution method. In section 5, I present the quantitative results of the model and in section 6 explain the main transmission mechanism of QE. Section 7 presents the paper's main results, where I simulate the crisis and present the different exit strategies from QE. Finally, section 8 concludes.

2 COVID-19 crisis and policy response in the US

In March 2020, the COVID-19 pandemic hit economies worldwide, generating an unprecedented macroeconomic crisis. As a response, central banks in leading developed economies, particularly the US, started to stimulate the economy through cuts in short-term interest rates until they touched the zero lower bound. In parallel, central banks started Quantitative Easing programs. It consisted of purchasing assets, mainly treasuries of long maturity, expanding their balance sheet at a breakneck speed. As shown in figure 1, the assets in the Federal Reserve increased from 4 trillion dollars in the third quarter of 2019 to around 8 trillion dollars one year later.

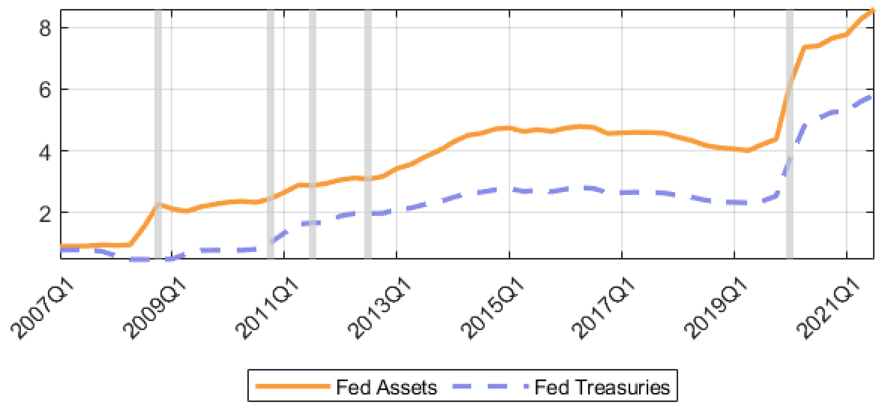

Figure 1: Federal Reserve Balance Sheet

Assets in the Federal Reserve balance sheet (orange line) and treasuries in the balance sheet (dotted light-blue line). Variables in trillions of dollars. Source: FRED and US Financial Accounts. Grey vertical lines show the start of a Quantitative Easing program.

The Quantitative Easing program took place with a massive expansion in total debt issuance from the treasury. Figure 2 shows net purchases of treasuries from the start of the COVID-19 crisis. They are net flows of treasuries, i.e., net of revaluation effects that take into account the change in treasuries' prices[5]. Different colors represent different agents in the economy. When the bar is above zero, the agent purchased treasuries during the period, while if it is below zero, it represents net sales. The blue line represents the net debt issuance from the US Treasury, which is the sum of all the bars in a corresponding period.

That figure shows that the monetary authority's purchases of government bonds played a vital role during this period, sustaining the demand for treasuries when main economic agents like the household sector, mutual funds, and the rest of the world were selling their bond holdings. Furthermore, together with the evidence in Vissing-Jorgensen (2021), we can argue that the FED purchases provided fiscal space in the short run, allowing the fiscal authority to accommodate a fiscal shock while maintaining the price of debt at high levels.

[5]The conclusions do not change when we consider changes in treasuries. See Appendix, section 9.1.

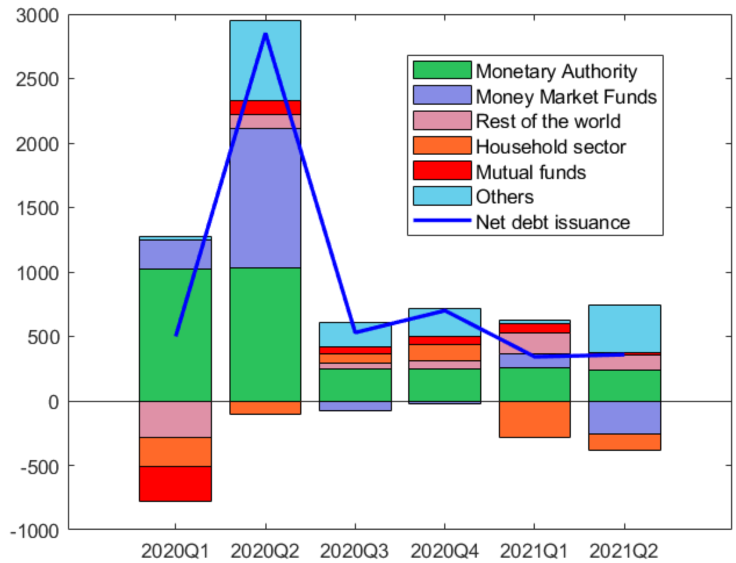

Figure 2: Net purchases of treasuries

Source: US Financial Accounts. Data in billions of dollars. Flows, net of revaluation effects.

Who sells treasuries to the central bank during a QE operation has implications regarding the primary macroeconomic aggregates in the economy. When the FED performs quantitative easing policies, it purchases assets. The counterpart of this operation is the issuance of bank reserves (or money in commercial banks' hands) that increases the central bank's liabilities, expanding the central bank's balance sheet. If commercial banks were the original owners of the bonds (case 1), this operation would leave its balance sheet unchanged since they increase one asset (reserves) while decreasing another (treasuries). However, suppose the original owner of the bond was the non-bank private sector (case 2), like households or mutual funds. In that case, the bank is a mere intermediary of this policy. The result would be an increase in deposits or currency (money in private hands), together with an increase in reserves and the central bank's balance sheet. As a result, different measures of money increase after quantitative easing policies under different cases; either bank money in the form of reserves (case 1) or non-bank private money (case 2). This liquidity expansion, also emphasized by Cui and Sterk (2021), and the owner of this liquidity, shapes the transmission mechanism of QE policies.

In figure 3, we can see a great expansion in liquidity, both in the form of bank reserves and deposits[6]. Other measures of monetary aggregates present significant spikes during this period too. Some of these variables, like public debt, are at values over GDP not seen since the Second World War.[7]

As economies recover and face inflationary dynamics not seen in the last 40 years, it is unclear how to unwind the stimulus injected during the crisis. The combination of high inflation rates, large ratios of debt/GDP and liquidity, and expanded central bank balance sheet presents an extra challenge for policymakers. On the one hand, large central bank reserves imply higher interest payments when short-term interest rates rise, giving incentives to retire liquidity at a fast velocity. On the other hand, there is a great degree of uncertainty regarding the macroeconomic effects of reducing the balance sheet size.

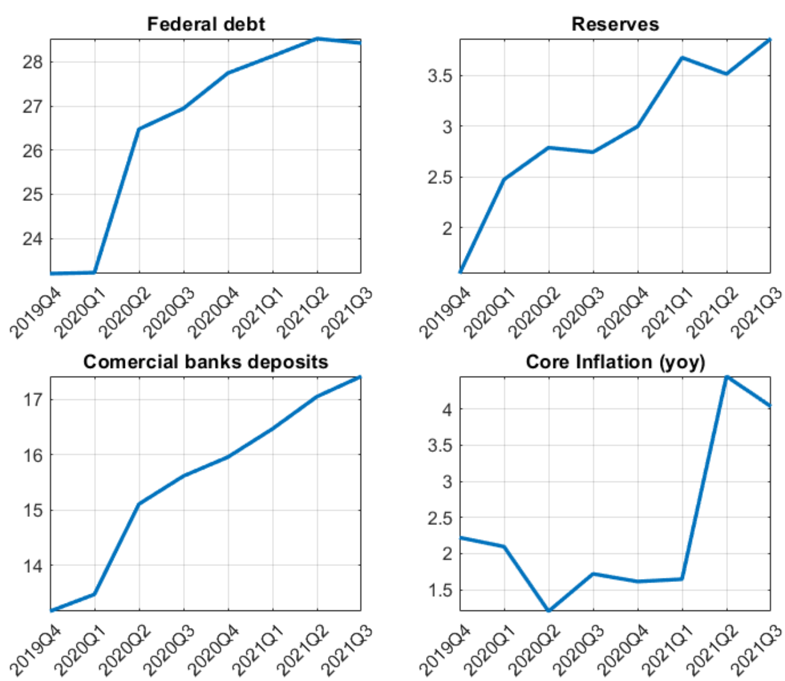

Figure 3: Macroeconomic variables: public debt, liquidity, inflation

US Federal Debt, Reserves and Deposits, in trillions of dollars. Core inflation in %. Source debt, deposits, and inflation data: FRED. Source reserves: US financial accounts, release December 2021.

[6] In the appendix, section 9.1, I show this last feature differs from what happened after the Quantitative Easing programs after the Great Recession.

[7] See section 9.1 for a historical plot of this variable.

In the following section, I present a model able to generate the comovements that we observed in aggregate macroeconomic variables during the COVID-19 crisis and the consequent policy response and use it as a laboratory to shed some light on this policy debate.

3 Model

The model is a Markov-Switching NK-DSGE model with five agents: Firms, households, Monetary Authority, Fiscal Authority, and financial intermediaries (FI). There are three assets in the economy: Short-term public bonds B_t^S, with one-period maturity and price Q_t^S; deposits D_t, which provide liquidity services to households, and with price Q_t^D; and long-term public bonds: B_t^L, with geometrically decaying maturity δ, as in Hatchondo and Martinez (2009). They pay a coupon κ every period, and their price is Q_t^L.

As is standard in the literature that assesses the transmission mechanisms of quantitative easing policies, there is segmentation in bond markets.[8] I follow Elenev et al. (2021) in assuming that households cannot invest in short-term public bonds held exclusively by financial intermediaries and the central bank. In contrast, financial intermediaries do not invest in long-term public bonds. Short-term bonds in the model stand for treasury bills and central bank reserves indistinctly since both assets share liquidity and return properties. The only difference between them is which governmental institution issues them (i.e., central bank or treasury). The assumption that financial intermediaries exclusively hold them in the model makes this asset close to "money in banks' hands."

Market segmentation interacts in the model with four frictions. First, prices are sticky, as in Rotemberg (1982) and the New-Keynesian literature. Second, deposits provide liquidity services to households, increasing their utility, as in the tradition of Money in the Utility (MIU) function models. I assume this friction is in terms of deposits since they are the most liquid asset the household can invest in this economy. Including variables that stand for reserves and monetary aggregates in the model, together with the frictions above, allows the model to generate the main macroeconomic effects of quantitative easing policies that

[8]See, for instance, Chen et al. (2012), and Bhattarai and Neely (Forthcoming) for a comprehensive analysis on different mechanisms to break the non-arbitrage condition between different assets in the economy, and thus, the neutrality result from Wallace (1981).

we observe in the data. Third, households pay a portfolio adjustment cost when purchasing long-term public bonds. Finally, financial intermediaries are subject to a leverage constraint that states that their debt (deposits) cannot be larger than their assets (reserves and treasury bills).

Two authorities constitute the government: the treasury and the central bank. Each authority has its budget constraint and policy instrument(s). The presence of the two governmental sectors allows the model to generate realistic policy interactions, which are at the center of macroeconomic dynamics. I follow Bianchi and Melosi (2017), and Bianchi and Melosi (2022) and assume that parameters in policy rules for conventional monetary policy, the Taylor rule, and fiscal rule alternate between regimes.

Next, I describe each agent and its optimization problem.

3.1 Households

There is a continuum of measure one of homogeneous households that live infinite periods in the economy. A representative agent chooses consumption c_t, labor n_t, deposits D_t^H, and long-term public bonds $B_t^{L,H}$ to maximize its lifetime utility:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \nu_t \beta^t U \left(c_t, \frac{D_t^H}{P_t}, n_t \right)$$

ν_t is a preference shock that follows an AR(1) process. Deposits are the most liquid asset that a household can purchase. I assume agents derive utility from the liquidity services this asset provides. The utility function is monotone increasing in consumption and deposits, monotone decreasing in labor, and satisfies Inada conditions on all variables.

Long-term bonds pay geometrically decaying coupons, as in Hatchondo and Martinez (2009). A bond B_t^L issued at time t, pays the sequence of coupons: κ, $\kappa(1-\delta)$, $\kappa(1-\delta)^2$, ..., where $\kappa > 0$ and $\delta \in (0, 1)$. This last parameter controls the debt maturity, where $\delta = 1$ corresponds to a short-term bond (i.e., 1-period maturity), and $\delta = 0$ represents a consol. This maturity specification reduces the number of state variables in the model. A bond issued at time $j - k$ is equivalent to $(1 - \delta)^k$ bonds issued at period t, and hence the state variable B^L_{t-1} represents total long-term debt in equivalent newly issued long-term bonds. Their price at period t is Q^L_t[9].

Every period, the representative household pays taxes (τ_t), receives nominal dividend payments from financial intermediaries Div_t, firm's profits since households are the owners Π^f_t, and rebates $\tilde{\Pi}_t$. When she invests in long-term bonds, she pays a portfolio adjustment cost of $\Phi(.)$ on top of the asset's price [10]

The optimization problem of a representative household is the following.

$$\max_{c_t, n_t, D^H_t, B^{L,H}_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \nu_t U\left(c_t, \frac{D^H_t}{P_t}, n_t\right)$$

$$\begin{aligned} P_t c_t + Q^D_t D^H_t + B^{L,H}_t Q^L_t + \Phi_L\left(\frac{B^{L,H}_t}{P_t}\right) P_t &= W_t n_t + D^H_{t-1} + \cdots \\ +B^{L,H}_{t-1}\left[\kappa + (1-\delta)Q^L_t\right] &+ \Pi^f_t + Div_t + \tilde{\Pi}_t - \tau_t P_t \end{aligned} \tag{1}$$

$$D^H_t \geq 0$$

$$B^{L,H}_t \geq 0$$

P_t price level, W_t is the nominal wage. Under this specification, the expected return on a long-term bonds purchased at period t is: $R^L_{t,t+1} = \mathbb{E}_t \frac{\kappa + (1-\delta)Q^L_{t+1}}{Q^L_t}$.

Notice that the non-negativity condition on deposits does not bind at the optimum even if they pay a lower return, given the assumption that deposits increase utility. Finally, the last constraint is the non-negativity conditions for public bonds since the household cannot go short on them.

Associate the multiplier $\beta^t \lambda_t$ to the budget constraint. The system of equilibrium conditions that characterize the households' optimization problem solution is the following:

[9] Notice that the deflated number of nominal bonds by the price level, $\frac{B^{L,H}_t}{P_t} = b^{L,H}_t$ is not the real value of public debt. Instead, the real value of public bonds held by households is $Q^L_t \frac{B^{L,H}_t}{P_t}$. As discussed in Leeper et al. (2021), introducing the variable $b^{L,H}_t$ allows to dispose of one variable, by working with $b^{L,H}_t$ instead of P_t and $B^{L,H}_t$.

[10] This assumption helps the model generate a positive term premium in long-term public bonds.

$$\frac{-U_n\left(c_t, \frac{D_t^H}{P_t}, n_t\right)}{U_c\left(c_t, \frac{D_t^H}{P_t}, n_t\right)} = \frac{W_t}{P_t}$$

$$Q_t^D = \mathbb{E}_t \mathcal{M}_{t,t+1} + \frac{U_d\left(c_t, \frac{D_t^H}{P_t}, n_t\right) P_t}{U_c\left(c_t, \frac{D_t^H}{P_t}, n_t\right)}$$

$$Q_t^L + \Phi_L'\left(\frac{B_t^{L,H}}{P_t}\right) = \mathbb{E}_t \mathcal{M}_{t,t+1}\left[\kappa + (1-\delta) Q_{t+1}^L\right]$$

Where $\mathcal{M}_{t,t+1}$ is the stochastic discount factor between period t and $t+1$.

$$\mathcal{M}_{t,t+1} = \beta \mathbb{E}_t \frac{\lambda_{t+1}}{\lambda_t} = \beta \mathbb{E}_t \frac{U_c\left(c_{t+1}, \frac{D_{t+1}^H}{P_{t+1}}, n_{t+1}\right)}{U_c\left(c_t, \frac{D_t^H}{P_t}, n_t\right)} \frac{1}{\pi_{t+1}}$$

Together with the budget constraint (1), they characterize the solution to the household's optimization problem[11]. Define $\pi_t = \frac{P_t}{P_{t-1}}$ as the inflation rate of period t. Notice that even without the presence of portfolio adjustment cost, a spread will exist between the prices of deposits and long-term bonds. households are willing to invest in deposits, even though they provide a lower return because they derive utility from them. The presence of portfolio adjustment costs in bonds generates a term spread and prevents the household from fully exploiting the arbitrage opportunities in the assets' markets. The literature has shown this feature to be vital for the transmission mechanism of quantitative easing policies.

For future reference, it is convenient to define the return on a risk-free private asset in this economy, which is in zero net supply, as given by:

$$R_t^N = \frac{1}{\mathcal{M}_{t,t+1}}$$

This is defined as the natural interest rate in Benigno and Benigno (2022), which differs from the policy rate, and is key in the consumption-savings trade-off.

[11]The non-negativity condition in public bond purchases ensures the transversality condition is satisfied.

3.2 Firms

The productive sector comprises two levels: final goods producers and intermediate goods producers.

3.2.1 Final good producer

A representative firm produces the domestic final good y_t from varieties y_i, for i $\in [0,1]$.

$$y_t = \left[\int_0^1 y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

Where ε is the elasticity of substitution between varieties. The optimization problem of the representative firm is the following:

$$\max_{y_t, \{y_{i,t}\}_{i\in[0,1]}} P_t y_t - \int_0^1 P_{i,t} y_{i,t} di$$
$$\text{s.t } y_t = \left[\int_0^1 y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$$

And the optimal demand function for variety i is given by the following expression:

$$y_{i,t} = y_t \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} \tag{2}$$

3.2.2 Intermediate goods firms

Intermediate goods firms are monopolistically competitive in the goods market. Each firm produces a variety i according to a linear production function:

$$y_{i,t} = z_t n_{i,t} \tag{3}$$

Where z_t is a mean reverting TFP shock, common to all varieties, with law of motion:

$$\ln(z_t) = \rho_z \ln(z_{t-1}) + \sigma_z \varepsilon_t^z,\ \varepsilon_t^z \sim N(0,1)$$

When changing prices, firm i is subject to a quadratic adjustment cost in prices, as in Rotemberg (1982):

$$\frac{\phi^P}{2}\left(\frac{P_{i,t}}{P_{i,t-1}}-\pi^*\right)^2 y_t$$

Where ϕ_P measures the degree of nominal price rigidity, and y_t is aggregate output, given by:

$$y_t=\int_0^1 y_{i,t}di$$

The nominal profit of firm i at period t, transferred to households, is given by:

$$\Pi^f_{i,t}=P_{i,t}y_{i,t}-W_t n_{i,t}-\frac{\phi^P}{2}\left(\frac{P_{i,t}}{P_{i,t-1}}-\pi^*\right)^2 y_t P_t \tag{4}$$

Firms maximize the discounted sum of profits using the households' discount factor, and subject to technology 3, and demand 2.

Their optimization problem is the following:

$$\max_{P_{i,t},n_{i,t}} \mathbb{E}_0 \sum_{k=0}^{\infty} \mathcal{M}_{t,t+k}\Pi^f_{i,t+k}$$

$$\text{s.t. } y_{i,t}=z_t n_{i,t}$$

$$y_{i,t}=y_t\left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon}$$

$$\Pi^f_{i,t}=P_{i,t}y_{i,t}-W_t n_{i,t}-\frac{\phi^P}{2}\left(\frac{P_{i,t}}{P_{i,t-1}}-\pi^*\right)^2 P_t y_t$$

In equilibrium, all firms behave symmetrically, and we have $P_{i,t}=P_t$. Thus, aggregate profits are given by:

$$\Pi^f_t=P_t y_t-W_t n_t-\frac{\phi^P}{2}\left(\pi_t-\pi^*\right)^2 y_t P_t$$

Their optimization problem is characterized by the following conditions, where MC_t is the multiplier of equation 2.

$$1-\varepsilon+\varepsilon\frac{MC_t}{P_t}=\phi_P\left(\pi_t-\pi^*\right)\pi_t-\phi_P\mathbb{E}_t\left[\mathcal{M}_{t,t+1}\frac{y_{t+1}}{y_t}\pi^2_{t+1}\left(\pi_{t+1}-\pi^*\right)\right] \tag{5}$$

$$W_t = MC_t z_t \tag{6}$$

The first condition is the New-Keynesian Phillips curve, where MC_t is the nominal marginal cost.

3.3 Financial intermediaries

In this section, I follow a simplified version of the financial intermediaries' description in Elenev et al. (2021).

A representative agent in this sector starts the period t with a net worth of W_t^I. Every period, it pays dividends to households, given by a fraction τ^I of its net wealth minus the equity raised that period: A_t.

$$Div_t = \tau^I W_t^I - A_t \tag{7}$$

This agent can invest in short-term public bonds $B_t^{S,I}$ at a price of Q_t^S. $B_t^{S,I}$ is the sum of treasury bills (treasuries with a maturity of up to a year, B_t^S) and central bank reserves ($B_t^{S,CB}$). The reason for adding these assets into one variable is that they have the same risk and return properties in the model, being perfect substitutes from the financial intermediaries' point of view. Its liabilities are given by deposits from households D_t^I. The following expression then gives the balance sheet:

$$(1 - \tau^I)W_t^I + A_t - \Phi_A(A_t) + Q_t^D D_t^I = Q_t^S B_t^{S,I} \tag{8}$$

Where $\Phi_A(.)$ is a convex cost of issuing new equity, rebated in a lump-sum fashion to the household.

The net wealth at period t is:

$$W_t^I = B_{t-1}^{S,I} - D_{t-1}^I \tag{9}$$

In line with Basel regulation, financial intermediaries are subject to a leverage constraint. It states that their debt (in this case, deposits) can be, at most, a fraction ζ of its assets[12].

$$D_t^I \leq \zeta B_t^{S,I} \tag{10}$$

The optimization problem of a financial intermediary consists on maximizing the discounted sum of dividends subject to restrictions 8, 9, and 10. I assume the financial intermediary discounts its future flows using the household's stochastic discount factor.

$$\begin{aligned} \max_{A_t, D_t^I, B_t^{S,I}} \mathbb{E}_0 \sum_{k=0}^{\infty} \mathcal{M}_{t,t+k} \left(\tau^I W_t^I - A_t \right) \\ \text{s.t. } (1-\tau^I) W_t^I + A_t - \Phi_A(A_t) + Q_t^D D_t^I = Q_t^S B_t^{S,I} \\ W_t^I = B_{t-1}^{S,I} - D_{t-1}^I \\ D_t^I \leq \zeta B_t^{S,I} \end{aligned}$$

Define η_t as the Balance sheet multiplier and μ_t as the Leverage constraint multiplier. Using the first order condition with respect to equity A_t to substitute out the multiplier η_t, we obtain the system of equations that characterize the financial intermediary's optimization problem, together with 7, 8, 9, 10 [13]:

$$Q_t^D = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \mu_t \left(1 - \Phi_A'(A_t)\right) \tag{11}$$

$$Q_t^S = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \zeta \mu_t \left(1 - \Phi_A'(A_t)\right) \tag{12}$$

Where $\tilde{\mathcal{M}}_{t,t+1}$ is the stochastic discount factor for financial intermediaries, defined as:

$$\tilde{\mathcal{M}}_{t,t+1} \equiv \mathcal{M}_{t,t+1} \left(1 - \Phi_A'(A_t)\right) \left(\tau^I + \frac{1-\tau^I}{1 - \Phi_A'(A_{t+1})} \right)$$

[12] I assume the financial intermediary sector assets are composed only by treasury bills and central bank reserves for simplicity. In a more complicated model, they could also purchase firms' bonds or provide loans to firms to finance capital purchases. This is the case in Elenev et al. (2021) and Benigno and Benigno (2021). The qualitative conclusions of this paper do not change when considering a more complicated version of the model, reducing to quantitative differences.

[13] See appendix, section 9.2 for further details.

Notice that the spread between deposits and short-term bonds is a function of the leverage constraint multiplier μ_t. Since $\zeta < 1$, the return on short-term bonds is higher than the short-term bonds when the leverage constraint binds.

3.4 Monetary Authority

The Central Bank performs conventional and unconventional monetary policies. The conventional monetary policy sets the short-term nominal interest rate R_t, subject to a Zero Lower Bound restriction. This rate is the inverse of the short-term public debt price:

$$R_t \equiv \frac{1}{Q_t^S} \tag{13}$$

The unconventional monetary policy consists of central bank balance sheet policies. In particular, the central bank purchases long-term government debt $B_t^{L,CB}$ in exchange for reserves ($B_t^{S,CB}$), as in the data since the great recession. The rules for setting these two instruments are provided in a following section.

The following expression gives the Central Bank's balance sheet:

$$\frac{B_{t-1}^{S,CB}}{P_t} + \frac{B_{t-1}^{L,CB}}{P_t}\left[\kappa + (1-\delta)Q_t^L\right] = Q_t^S \frac{B_t^{S,CB}}{P_t} + Q_t^L \frac{B_t^{L,CB}}{P_t} + \Lambda_t^{CB}$$

where Λ_t^{CB} are central bank remittances to the fiscal authority. I assume that profits Λ_t^{CB} are transferred to the fiscal authority. [14]

Finally, the central bank is subject to a revenue neutrality constraint, which is in line with the data. It states that when the central bank increases its assets by purchasing long-term bonds, it has to offset the operation by decreasing its net position of short-term assets.

$$Q_t^L B_t^{L,CB} + Q_t^S B_t^{S,CB} = 0 \tag{14}$$

When it performs QE, we have $B_t^{S,CB} < 0$, representing the increase in reserves issuance.

[14] For simplicity, in this paper I abstract from asymmetries in the transfer of the central bank's profits to the treasury.

3.5 Fiscal Authority

The treasury consumes g_t, and obtains resources from three different sources. It collects tax revenues from households in a lump-sun fashion, τ_t, receives dividends from the central bank Λ_t^{CB}, and issues debt, whose total real value is $\frac{B_t}{P_t}$. This debt comprises short-term bonds B_t^S, and long-term bonds B_t^L. The total debt issuance is[15]:

$$B_t = Q_t^S B_t^S + Q_t^L B_t^L \tag{15}$$

The period budget constraint of the fiscal authority, in real terms, is:

$$\underbrace{\tau_t - g_t}_{\equiv s_t} + \frac{B_t}{P_t} + \Lambda_t^{CB} = \frac{B_{t-1}^S}{P_t} + \frac{B_{t-1}^L}{P_t}\left[\kappa + (1-\delta)Q_t^L\right]$$

Where s_t is the real primary fiscal surplus of period t. Replacing Λ_t^{CB} from the central bank balance sheet and using 14, I obtain a consolidated budget constraint:

$$s_t + \frac{B_t}{P_t} = \underbrace{\frac{B_{t-1}^S - B_{t-1}^{S,CB}}{P_t}}_{A} + \underbrace{\frac{B_{t-1}^L - B_{t-1}^{L,CB}}{P_t}}_{B}\left[\kappa + (1-\delta)Q_t^L\right] \tag{16}$$

The terms 'A' and 'B' are the outstanding short and long-term public debt in the private's hands. Notice that through the purchases of long-term public bonds, the central bank relaxes the budget constraint for the consolidated government. However, this is not necessarily the case when considering the net position of short-term assets. For instance, if $B_t^{S,CB} < 0$, implying reserves issuance, then the consolidated government debt of short maturity is increasing with this policy. In this sense, quantitative easing policies can be interpreted as a maturity swap, exposing the government to interest rate risk.

The following expression gives government consumption:

$$g_t = \theta(y^* - y_t) + (1-\rho_g)\bar{g} + \rho_g g_{t-1} + \sigma_g \varepsilon_t^g,\ \varepsilon_t^g \sim N(0,1)$$

[15] Notice that the real amount of short-term bonds is $Q_t^S \frac{B_t^S}{P_t}$ and the one of long-term bonds is $Q_t^L \frac{B_t^L}{P_t}$.

$0 < \theta < 1$ represents the government spending reaction to output deviations from its steady state. This term generates a counter-cyclical behavior of government consumption, introducing fiscal stimulus when the economy is in recession. Government consumption goods are thrown into the ocean. Finally, the maturity composition of newly issued government debt is constant in book value terms, with a fraction $\bar{\mu}$ of debt being long-term.

$$\frac{B_t^S}{B_t^L} = \frac{1-\bar{\mu}}{\bar{\mu}} \tag{17}$$

3.6 Market clearing conditions

Market clearing conditions are the following:

$$c_t + g_t + \frac{\phi_P}{2}\left(\pi_t - \pi^*\right)^2 y_t = y_t$$
$$D_t^H = D_t^I$$
$$B_t^S - B_t^{S,CB} = B_t^{S,I}$$
$$B_t^L = B_t^{L,H} + B_t^{L,CB}$$

And households' rebates by other agents in the model are equal to:

$$\tilde{\Pi}_t = \Phi_L\left(b_t^{L,H}\right) + \Phi_A(A_t)$$

3.7 Policy rules

To close the model, I assume that fiscal and monetary authorities follow rules to set the policy instruments: τ_t, R_t and $b_t^{L,CB}$. First, I assume that central bank purchases of long-term bonds follow an AR(1) process:

$$b_t^{L,CB} = (1-\rho^{QE})b_*^{L,CB} + \rho^{QE} b_{t-1}^{L,CB} + \sigma^{QE}\epsilon_t^{QE} \tag{18}$$

Where $b_*^{L,CB}$ is the average amount of long-term bonds at the steady state. Increases in the central bank balance sheet are random and unrelated to the economic conditions.

I follow this assumption for two reasons. First, this paper aims to study the effects of quantitative easing policies under different interactions of conventional fiscal and monetary policies. Second, there is no evidence or consensus of a clear rule for central bank purchases, being a policy used with a greater discretionary component. This assumption implies that QE constitutes a complementary policy instrument of the central bank and not necessarily a substitute, in line with what we observe in the data. Furthermore, it prevents the instrument from altering the determinacy properties of the model.

I follow the literature on fiscal-monetary policy interactions and assume that fiscal and monetary authorities follow rules to determine the conventional policy instruments. In particular, the nominal short-term interest rate follows the Taylor rule 20, reacting to output and inflation deviations from its steady state values, together with an autoregressive parameter ρ_R and a monetary shock ϵ_t^m with standard deviation σ_t^m. The monetary shock stands for interest rate deviations from the reaction function. The intensity of interest rate reaction to output and inflation deviations are characterized by policy parameters α_y and α_π, respectively. Finally, $\bar{R}$ is the mean of the nominal interest rate.

For fiscal policy, I assume that taxes τ_t react to total real debt deviations from its steady state value b, and have an autoregressive coefficient ρ_τ, as in 19. The elasticity of tax deviations to debt deviations is characterized by the parameter γ.

$$\tau_t - \tau^* = \rho_\tau(\xi_t)(\tau_{t-1} - \tau^*) + (1 - \rho_\tau(\xi_t))\gamma(\xi_t)(b_{t-1} - b^*) \tag{19}$$

$$\frac{R_t}{\bar{R}(\xi_t)} = \left(\frac{R_{t-1}}{\bar{R}(\xi_t)}\right)^{\alpha_R(\xi_t)} \left[\left(\frac{\pi_t}{\pi^*}\right)^{\alpha_\pi(\xi_t)} \left(\frac{y_t}{y^*}\right)^{\alpha_y(\xi_t)}\right]^{1-\alpha_R(\xi_t)} e^{\sigma_M(\xi_t)\epsilon_t^M} \tag{20}$$

The parameters above depend on a discrete shock ξ_t, that follows a Markov process. I follow Bianchi and Melosi (2017) and assume that this shock can take three values, representing the three regimes through which the economy fluctuates.

The first regime, the *monetary-led (M)* regime, is characterized by a strong interest rate reaction to inflation deviations (high α_π), and a strong tax reaction to debt (high enough

γ)[16]. This regime is associated to an *active monetary policy* and *passive fiscal policy*, in Leeper (1991) terminology. Under this regime, the monetary authority accommodates the nominal interest rate more than proportionally to changes in the inflation rate to stabilize inflation. At the same time, the treasury passively adjusts taxes to stabilize the real debt.

The second regime is the *fiscally-led regime (F)* where the fiscal authority's main objective is to stabilize the economy and not the real debt (low γ). Then the central bank allows the inflation rate to deviate from the target to stabilize debt in real terms. This regime can be defined as *passive monetary policy* and *active fiscal policy* in the sense of Leeper (1991).

The third regime is the *Zero Lower Bound regime* (ZLB). It is characterized by an unreactive nominal short-term interest rate that remains fixed at its effective lower bound and by a fiscal policy that is unreactive to the real debt level. This regime is an extreme form of the fiscally led regime since we have $\alpha_\pi = \gamma = 0$. As in Bianchi and Melosi (2017), this regime represents a *crisis regime*, where the economy enters due to the realization of bad shocks that drive the economy to a recession. However, differently from Bianchi and Melosi (2017), the economy enters the zero lower bound regime endogenously when the central bank cannot decrease the short-term interest rate further due to a lower bound.

3.8 Transition probabilities

Assume the Markov-switching shock ξ_t depends on the realization of two random variables ξ_t^P and ξ_t^C. When $\xi_t^C = 1$, the economy suffers a crisis and moves to the zero lower bound regime. When $\xi_t^C = 0$, the economy is in *normal times*, and the government can set fiscal and monetary policies without restriction. In this case, the variable ξ_t^P determines the regime in place stochastically. $\xi_t^P = M$ stands for the monetary led regime, $\xi_t^P = F$ for the fiscally led regime, and it evolves according to the transition matrix:

$$PP = \begin{bmatrix} p_{mm} & 1 - p_{mm} \\ 1 - p_{ff} & p_{ff} \end{bmatrix}$$

[16] In Appendix, I present, for a given calibration, the combinations of values α_π and γ that give rise to determinacy at each regime. Notice, however, that the global stability of the system does not require determinacy at each regime.

where $p_{ij} = P\left(\xi_{t+1}^P = j | \xi_t^P = i\right)$

As seen from the transition matrix PP, the probability of being in one regime or another is constant and entirely exogenous during normal times. The realization of this shock represents, in a simplified way, the outcome of a policy game between the fiscal and the monetary authority, where the winner is the 'active' authority.

Define q as the probability of entering to the ZLB regime, $q = P(\xi_{t+1}^C = 1 | \xi_t^C = 0)$ and r as the probability of moving out of the crisis regime $q = P(\xi_{t+1}^C = 0 | \xi_t^C = 1)$.

The transition matrix for ξ_t is then:

$$P = \begin{bmatrix} (1-q)PP & q[1;1] \\ r[p_{zm};(1-p_{zm})] & (1-r) \end{bmatrix}$$

Where p_{zm} is the probability of exiting the ZLB regime towards a monetary-led regime. q and r are endogenous processes. The probability of entering the ZLB regime is a decreasing function of the nominal interest rate:

$$q = P(\xi_{t+1}^C = 1 | \xi_t^C = 0) = f(R_t)$$

Intuitively, it is a function that generates zero probability of switching when the gross nominal interest rate is higher than one, and it increases the R_t approaches the value of 1.

The probability of leaving the crisis regime, r, is a function of a shadow interest rate R_t^S:

$$r = P(\xi_{t+1}^C = 0 | \xi_t^C = 1) = g(R_t^S)$$

The shadow interest rate represents the interest rate that would hold in the economy if this were always in the monetary-led regime, without a lower bound restriction:

$$\frac{R_t}{\bar{R}\left(\xi_t^P = M\right)} = \left(\frac{R_{t-1}}{\bar{R}\left(\xi_t^P = M\right)}\right)^{\alpha_R\left(\xi_t^P = M\right)} \left[\left(\frac{\pi_t}{\pi^*}\right)^{\alpha_\pi\left(\xi_t^P = M\right)} \left(\frac{y_t}{y^*}\right)^{\alpha_y\left(\xi_t^P = M\right)}\right]^{1-\alpha_R\left(\xi_t^P = M\right)} e^{\sigma_M\left(\xi_t^P = M\right)\epsilon_t^M} \tag{21}$$

This assumption reflects that the probability of leaving the zero lower bound regime is not independent of the economic conditions. For instance, when output and/or inflation recovers, the

Shadow interest rate increases, increasing the likelihood that the central bank would start raising interest rates.

Endogenous transition probabilities to and out of the zero lower bound matter for agents' expectations. Contrary to an entirely exogenous transition matrix model, agents know the likelihood of tightening monetary policy increases with output and inflation even at the zero lower bound.

4 Functional forms, calibration and solution

4.1 Functional forms

In this section, I present the functional forms assumed in the numerical exercise. I assume the following CRRA utility function for households, which depends positively on consumption and deposits and negatively on labor.

$$U(c_t, d_t^H, n_t) = \frac{\left[c_t^{1-\varphi}\left(d_t^H\right)^{\varphi}\right]^{1-\sigma}}{1-\sigma} - \psi \frac{n_t^{\eta}}{\eta}$$

Where $d_t^H = \frac{D_t^H}{P_t}$ are deposits deflated by the price level.

The portfolio adjustment cost for long-term bonds is quadratic:

$$\Phi_L\left(b_t^{L,H}\right) = \frac{\phi_L}{2}\left(\frac{b_t^{L,H}}{b^{L,H}}\right)^2$$

where $b_t^{L,H} = \frac{B_t^{L,H}}{P_t}$, and $b^{L,H}$ is the steady state value of public long-term bonds held by households.

The convex cost of issuing equity is the following:

$$\Phi_A(A_t) = \frac{\chi}{2}\frac{A_t^2}{P_t}$$

Finally, the endogenous transition probabilities to and out of the zero lower bound regime are assumed to follow a logistic distribution as in Benigno et al. (2020), and Bocola (2016). As in their models, the economy's transition between regimes is a logistic function of a subset of the model's endogenous variables. In this case, they are given by the following expressions:

$$q = P(\xi_{t+1}^C = 1|\xi_t^C = 0) = \frac{\exp\left\{-\gamma^q \left(R_t - 1\right)\right\}}{1 + \exp\left\{-\gamma^q \left(R_t - 1\right)\right\}}$$

where $\gamma^q > 0$ is a constant. And,

$$r = P(\xi_{t+1}^C = 0|\xi_t^C = 1) = \frac{\exp\left\{-\gamma^r \left(R_t^S - 1\right)\right\}}{1 + \exp\left\{-\gamma^r \left(R_t^S - 1\right)\right\}}$$

with $\gamma^r < 0$.

4.2 Calibration

I work with quarterly data for the US. In this section, I present the calibration. In table 1, I present the calibration of structural parameters with their source or target. Some parameters have direct counterparts in the data. For instance, $\bar{R}$, the average gross short-term nominal interest rate is set equal to 1.011, as in quarterly data for the period 1980-2021.[17] The average of long-term public bonds purchased by the central bank, $b_*^{L,CB}$ is set to 0.014 to match the average 7% annual ratio of Federal Reserve total treasuries to output ratio, in market value terms, for the period 1980-2021. Finally, the parameter that characterizes the collateral ratio in the financial intermediaries' leverage constraint, ζ, is set to 0.97 as in the Basel regulation[18].

Some parameters are taken from the literature. For instance, the risk aversion parameter σ is set to 2, as is standard in the literature. The inverse of Frisch elasticity η, is set to 3 as in Leeper et al. (2021), $\bar{\mu}$, that is the proportion of long-term bonds in book values issued by the treasury, is 0.67 as in Elenev et al. (2021) and θ, that is 0.27 as in Bianchi and Melosi (2017). The convex cost of issuing equity for financial intermediaries, χ is 22 as in Elenev et al. (2021). The coupon payment of long-term bonds, κ, that includes the interest and the matured part fraction of bonds is normalized to 1.

Other parameters are calibrated to match first-order moments in the data. β takes the value 0.996 to match the average return of a real risk-free asset from Jordà et al. (2017). δ is set to 0.0357 to roughly match the average maturity of public bonds with a maturity longer than one year, seven years. The parameter that characterizes the quadratic portfolio adjustment cost of long-term bonds,

[17]Notice that, in the data, this value corresponds to the average nominal interest rate, including periods where the interest rate was at the effective lower bound.

[18]In the data, the balance sheet of financial intermediaries includes a broader set of assets that can be used as collateral, than the ones included in the model (T-bills and central bank reserves). This assumption, although restrictive since it introduces a tight relationship between deposits and reserves, is maintained for simplicity.

ϕ_L is calibrated to 0.0039 to match the average spread between long and short-term bonds of 0.32% in the period 1980Q1-2021Q4 at the steady state[19].

	Description	Value	Source or target
β	Discount factor	0.996	Jordà et al. (2017)
R^*	Average interest rate	1.011	Av. Data 1980-2021
$\bar{\mu}$	Proportion of long-debt	0.67	Elenev et al. (2021)
δ	Maturity parameter	0.0357	Maturity long bonds (7 years)
κ	Coupon Payment	1	Normalization
ϕ_L	Portfolio adjustment cost	0.004	10-year yield (1980-2021)
σ	Risk aversion	2	Standard
η	Inverse Frisch elasticity	3	Leeper et al. (2021)
ψ	Preference parameter	1.339	Normalization labor
φ	Preference parameter	0.0023	Debt/GDP $\frac{b}{4y}$ = 68% 1980-2021
τ^I	Dividends distribution	0.84	Spread T-bill to deposits
χ	Equity cost	22	Elenev et al (2021)
ζ	Leverage constraint FI	0.97	Basel regulation
ϕ^P	Prices adjustment cost	150	Inflation volatility (1980-2021)
ϵ	Elasticity of subst. varieties	7	Markup 17%
$b_*^{L,CB}$	Average CB Balance sheet	0.014	$\frac{Q^L b_*^{LC,B}}{4y}$ = 7% 1980-2021
θ	Government spending	0.27	Bianchi and Melosi (2017)

Table 1: Calibration: model parameters

The preference parameter φ is set to 0.0023 to generate a simulated mean of annualized debt to GDP ratio close to the one in the data before the COVID-19 crisis, around 70% in 2020Q1. The fraction of financial intermediaries' wealth paid to households as dividends is calibrated to 0.84 to match the average spread between short-term interest rate and deposits of 0.31% from Drechsler et al. (2017)[20]. The elasticity of substitution between varieties ϵ is set to 7, generating an average markup of 17%, and the parameter ϕ^P that characterizes Rotemberg adjustment costs is set to 150 to roughly match the average inflation standard deviation during the period 1980-2021. Finally, the preference parameter ψ is calibrated to normalize labor to one at the steady state.

Table 2 presents the calibration for persistence and standard deviation of the exogenous processes in the model. They were jointly calibrated to match some second-order moments in the data for

[19]This spread in the model is the difference between the return on the long-term bond $R^L = \frac{\kappa+(1-\delta)Q^L}{Q^L}$ and the short-term interest rate R.

[20]The model does not prevent the net return on deposits to be negative at the zero lower bound regime. This could be motivated by the data, with the fact that during this period, although banks did not charge fees on deposits, some of them increased their account maintenance charges to customers.

the period 1980-2021. The comparison between moments in the data with the simulated moments is presented in the following section.

Parameter	Description	Value
ρ_{QE}	Persistence QE	0.9
ρ_{ν}	Persistence preference	0.9
ρ_z	Persistence TFP	0.9
ρ_G	Persistence gov. spending	0.96
σ_{QE}	Dispersion QE	0.0025
σ_{ν}	Dispersion preference	0.008
σ_z	Dispersion TFP	0.002
σ_G	Dispersion gov. spending	0.0026

Table 2: Calibration: exogenous processes

Table 3 presents the regime-switching parameters correspondent to the fiscal and monetary policy rules from section 3.7. The first set of parameters corresponds to the Taylor rule 20, and the correspondent parameters at each regime. The second set corresponds to the parameter values for the Shadow interest rate 21. These parameters are equal to the Taylor rule's parameters at the monetary regime, and they are not regime-dependent. They were included in the table for completeness. The third set of parameters in this table corresponds to the fiscal rule 19. The parameters in this table, with the exception of mean interest rates in all regimes, come from Bianchi and Melosi (2017). Since a parameter estimation goes beyond the scope of this paper, I take the parameters correspondent to conventional fiscal and monetary policy rules from this article that presents the same regimes and performs a Bayesian Estimation of the correspondent parameters using data for the US until the Great Recession.The average interest rate out of the zero lower bound is $\bar{R}$, explained in table 1. At the zero lower bound, I set the average interest rate to 1.0005, as the average quarterly Effective federal funds rate observed in the period: 2008Q4-2017Q1 and 2020Q1-2022Q1.

	Description	MD	FD	ZLB
α_R	Taylor rule	0.86	0.67	0.2
α_π	Taylor rule	1.6	0.64	0
α_y	Taylor rule	0.51	0.27	0
σ^M	Taylor rule	0.25/100	0.25/100	0.25/1000
R	Taylor rule	R^*	R^*	1.0005
$\alpha_{R,s}$	Shadow R	-	-	0.86
$\alpha_{\pi,s}$	Shadow R	-	-	1.6
α_y	Shadow R	-	-	0.9
$\sigma^{M,s}$	Shadow R	-	-	0.0025
R^S	Shadow R	R^*	R^*	R^*
γ	Fiscal rule	0.0712	0	0
α_τ	Fiscal rule	0.96	0.69	0.69

Table 3: Calibration: regime-dependent policy parameters .

Table 4 presents parameters relative to transition probabilities between regimes. Exogenous parameters from matrix P, p_{mm} and p_{ff} come from Bianchi and Melosi (2022). The probability of exiting the zero lower bound towards a monetary-led regime, p_{zm}, is set to 0.7031, and it comes from Bianchi and Melosi (2022). In this paper, the authors show that this probability significantly decreased after the COVID-19 crisis. Since this paper aims to study the exit strategies from the crisis and policies applied during that period, I considered the latest value of this estimated probability. However, the results do not significantly differ in a model with lower p_{zm}.

Parameters γ^r and γ^q give the steepness of the logistic function. They were calibrated to obtain a similar ergodic probability of the ZLB regime as in Bianchi and Melosi (2022) and to minimize the cases in which the economy is at this regime with a gross interest rate below one.

Parameter	Value	Source or target
p_{mm}	0.9923	Bianchi and Melosi (2022)
p_{ff}	0.9923	Bianchi and Melosi (2022)
p_{zm}	0.7031	Bianchi and Melosi (2022)
γ^q	500	Average prob. of ZLB regime
γ^r	-200	Average prob. of ZLB regime

Table 4: Calibration: transition probabilities

Figure 4 shows the corresponding probabilities for values of the nominal interest rate (left) or shadow interest rate (right) between 0.95 and 1.02. A positive value for γ^q generates a higher probability of entering the zero lower bound when the interest rate is below one and lower when it is above one. Notice that for this calibration, the probability of entering this regime when R is 0.987 or lower is one.

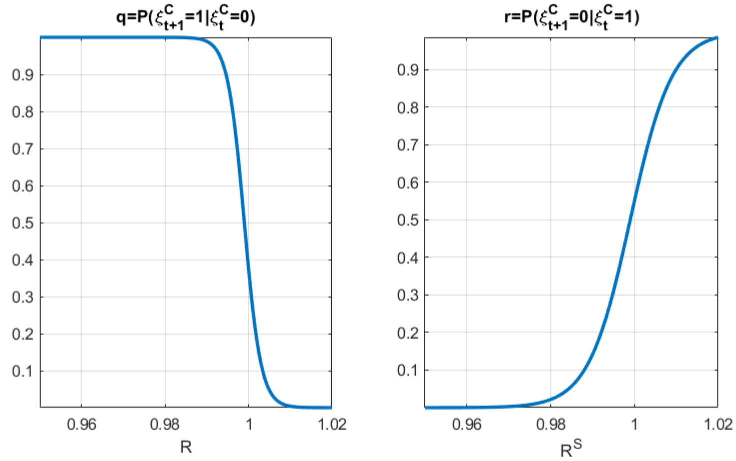

Figure 4: Endogenous transition probabilities to and out the zero lower bound.

For the probability of exiting the zero lower bound, the parameter γ^r is negative, generating a monotone increasing probability of leaving the crisis regime when the Shadow interest rate is higher.

4.3 Solution method

I solve the model in real terms through second-order perturbation methods for endogenous Markov Switching DSGE models, following Benigno et al. (2020). In the solution, I assume the leverage constraint for financial intermediaries is binding in all regimes. The approximation point for the solution method consists of a weighted average of steady states in different regimes, as authors in Benigno et al. (2020) explain. The weights are the ergodic means of corresponding regimes. In appendix 9.4, I present the steady state equations and describe the approximation point.

5 Quantitative Results

5.1 Second order moments

In this section, I present some second-order moments for selected variables to evaluate how the model performs in terms of generated volatility and cyclical properties. Data variables were demeaned to make them comparable with their model counterpart, where there is no growth. Empirical moments were calculated using quarterly data for the period 1980Q2-2021Q3. NIPA variables are real and per capita. Debt, inflation, and interest rate are annualized. Data moments were calculated from a simulation of one million periods, and they correspond to averages of the three regimes.

The following table compares the standard deviation (in %) and correlation with output growth. Output, consumption, and debt are logarithmic differences. Inflation and term spread are annualized gross rates.

	d Ln y_t	**d Ln c_t**	**d Ln $b_t^S + b_t^L$**	**Inflation**	**Term spread**
Standard deviation (in %)					
Data	1.3	1.4	1.7	2.8	1.6
Model	0.7	0.9	1.5	2.4	1.5
Correlation with d Ln y_t					
Data	1.00	0.90	-0.33	0.44	-0.11
Model	1.00	0.79	-0.32	0.27	-0.04

Table 5: Second order moments in data and model

Note: Growth rates for output, consumption, and debt in the data are quarterly logarithmic differences and demeaned. They are real and per capita. Inflation is the quarterly logarithmic difference, annualized. The term spread is the difference between the annual 10-year treasury yield and the annual federal funds rate. Model moments were obtained from a simulation with one million periods.

As can be seen from the table, the model generates the correct ranking in volatilities and standard deviation for debt, inflation, and spread, similar to the ones in the data. It generates around half of the volatility in output and consumption. This could be improved in a more complicated model with capital accumulation or a broader set of shocks. In terms of cyclical properties, the model generates the correct sign in correlation with output for all the variables in the table and close magnitudes to the empirical ones.

5.2 Conditional second order moments at different regimes

Table 6 show means and volatility measures for debt to GDP ratio, inflation, nominal short-term interest rate (R_t) and nominal return on long-term bonds (R_t), conditional on regimes. They reflect features typically highlighted by the literature that studies fiscal-monetary policy mix[21]. The fiscal regime is characterized by higher debt to GDP ratio, interest rates, and more volatile inflation and interest rate. Real debt to GDP, on the contrary, is more volatile in the monetary-led regime. The

[21] See, for instance Bianchi et al. (2020), where the authors estimate a Markov-Switching VAR with three regimes for the period 1960-2014.

ZLB is characterized by a very stable short-term interest rate close to one and almost nil inflation but quite volatile (standard deviation 2.6%).

	MD		**FD**		**ZLB**	
	Mean	**Std(%)**	**Mean**	**Std(%)**	**Mean**	**Std(%)**
Debt to GDP	69%	7.2	78%	3.8	71%	6.0
Inflation	1.02	1.7	1.02	4.0	1.01	2.6
Interest rate (R)	1.03	1.5	1.04	2.6	1.00	0.2
Long-run return (R^L)	1.04	1.5	1.05	3.1	1.02	1.8

Table 6: Data moments conditional on regimes

Note: Data generated moments, from a sample of one million periods. The model is simulated for a long sample where the regime is stochastic. Moments at each regime are obtained conditioning the economy being on the corresponding regime at a given period. Debt to GDP is $\frac{b}{4y}$, inflation, and returns are annualized since the model is solved quarterly.

6 The transmission mechanism of Quantitative Easing

This section sheds light on the model's transmission mechanism of an increase in central bank bond purchases, $b_t^{L,CB}$, given by an exogenous shock ϵ_t^{QE}, following 18. I show the log deviations (in %) of a simulated path for endogenous variables when there is a one standard deviation shock in the central bank purchases of long-term bonds to a counterfactual without the shock. This shock implies increasing the real balance sheet to GDP ratio by 1.3p.p., i.e., rising from its steady state of 7% to 8.3%, a conservative shock. I consider three different scenarios, where the economy is at a given regime and remains at the same regime for 16 quarters in both paths (with and without the shock). Even though there is no regime change in the simulation exercise, agents in the economy expect the economy to evolve according to the transition matrix 3.8.

6.1 Regime dependent Quantitative Easing shock

Figures 5 and 6 show the evolution of endogenous variables at monetary-led regime (continuous blue line, named 'M'), fiscally-led regime (dotted red line, named 'F') and zero lower bound regime (dashed yellow line, names 'ZLB'). They are presented as log deviations from a path without an increase in central bank purchases, in percentage[22].

When the central bank increases its purchases of long-term bonds ($b_t^{L,CB}$), it increases the size of its balance sheet, defined as $b_t^{L,CB} Q_t^L$. Due to the revenue neutrality constraint, it does it through the issuance of reserves to financial intermediaries. QE transmission mechanism operates through two channels in this model. First, when the central bank introduces reserves in the intermediary sector, it relaxes its leverage constraint 10, allowing them to increase the deposit supply to households. Second, the central bank intervention in the long-term bond market drives its price up, and then the long-term yield ($\mathbf{E}_t R_{t,t+1}^L$) falls. This price increase gives households incentives to rebalance their portfolio, selling their long-term bonds and exchanging them for deposits. These mechanisms operate as a demand shock in this economy. The portfolio revaluation effect provides households with a wealth effect, increasing consumption. The fall in investment returns generates a substitution effect from savings to consumption. Both channels operate, increasing aggregate demand in this economy[23].

The increase in aggregate demand is inflationary. Since firms operate under monopolistic competition, they can react in two ways to the rise in demand: either increase prices or produce more. In the first case, they have to pay a price adjustment cost due to the presence of nominal rigidities in this model. In the second case, given a constant TFP, they need to hire more labor. This pressure on labor markets generates an increase in real wages and, thus, in firms' marginal costs. We see a combination of these effects in equilibrium, so salaries, labor, and output also increase.

[22] Notice that, as shown in the previous section, the ergodic mean of endogenous variables differs among regimes. In the absence of shocks, the resting point of these variables would be the ergodic mean. For this reason, I show the log deviations from the correspondent mean, not from the steady state, broadly defined as an equilibrium without shocks.

[23] A complementary interpretation for the substitution between consumption and saving decision in the model comes from looking at the "natural interest rate" as defined in Benigno and Benigno (2022). As the authors highlight in their paper, a key reason why quantitative easing policies have real effects on the economy is that the policy rate differs from the natural interest rate. The later is the one that drives consumption/savings decision, defined as $R_t^N = \frac{1}{\mathcal{M}_{t,t+1}}$, i.e., the return on a risk-free private asset assumed to be in zero net supply in this paper. When the central bank increases its purchases of long-term bonds, the natural interest rate falls, even though it is not under the direct control of the central bank. This shifts households' savings towards consumption and explains the increase in aggregate demand. The most significant fall in this variable occurs at the ZLB, where we can see that QE is more expansionary.

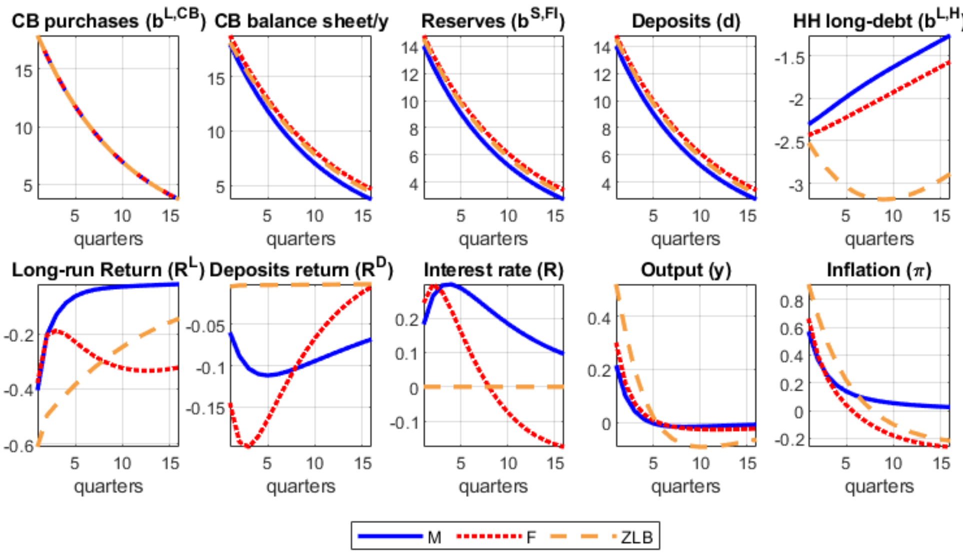

Figure 5: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the central bank purchases of long-term bonds ($\epsilon_t^{QE} = 1$) to the counterfactual path without shock ($\epsilon_t^{QE} = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods. The balance sheet to output ratio, interest rates, and inflation are annualized.

The intensity of these expansionary effects critically depends on the regime, being more expansive at the zero lower bound and, in second place, in the fiscally-led regime. At the zero lower bound, the fixed short-term interest rate exacerbates the substitution effect between savings and consumption. The short-term nominal interest rate increases in the fiscal and monetary-led regimes, following the corresponding Taylor rule. This return increase ameliorates the expansionary and inflationary effects of an increase in central bank purchases, especially in the monetary-led regime where the real short-term interest rate becomes positive.

Figure 6 shows the fiscal variables. Government debt behavior depends on the evolution of the three components of the government budget constraint: fiscal surplus, central bank remittances to the treasury, and debt service. First, the expansionary effect of central bank purchases triggers a fall in government spending due to automatic stabilizers. Hence, primary fiscal surplus increases on impact in all regimes. This effect is more significant in the zero lower bound, where output increases more. Central bank profits (Λ_t^{CB}) increase from period two in all scenarios, alleviating the pressure on fiscal accounts. Finally, total debt service behavior differs among regimes. Initially, it falls due to larger fiscal surpluses and remittances from the central bank, allowing the treasury to issue less debt (b^L, b^S). This effect is larger in the ZLB and fiscally led regime, where higher inflation rates give the government seigniorage revenues. However, the revaluation of long-term bonds is so strong in the fiscally-led regime that it dominates the effect on real debt (b_t), which increases.

The final result is an increase in fiscal space, interpreted as a fall in real debt (b_t) at the ZLB and the monetary regime. This effect is milder in the second, where taxes fall following debt issuance. In the fiscally-led regime, however, the revaluation effect on long-term bonds is so strong that the debt ratio to GDP increases.

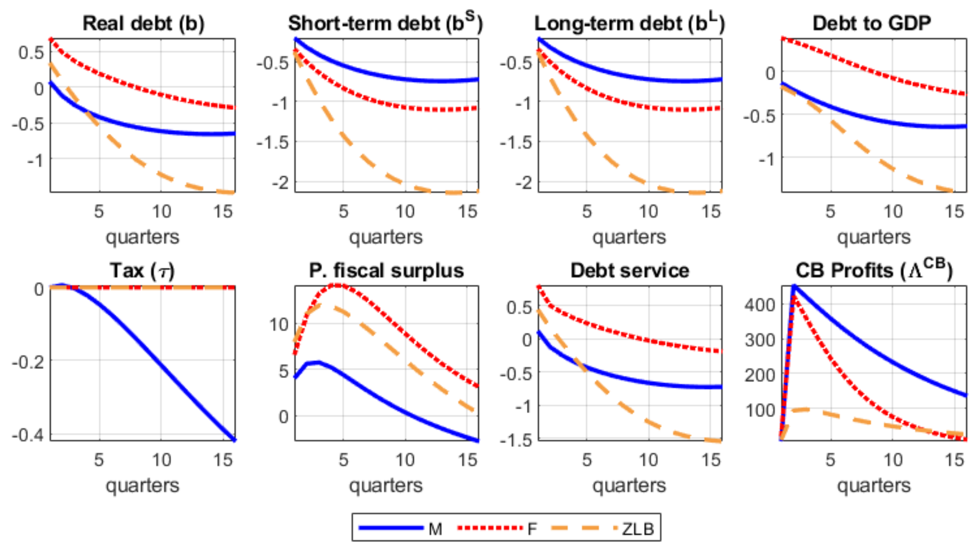

Figure 6: Impact of a Quantitative Easing shock conditional on a regime: fiscal variables

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the central bank purchases of long-term bonds ($\epsilon_t^{QE} = 1$) to the counterfactual path without shock ($\epsilon_t^{QE} = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods. Debt to GDP is annualized.

This exercise shows that the expansionary effects of quantitative easing policies are of considerate size under a crisis regime. At the zero lower bound, 1.3p.p. temporal increase in the central bank balance sheet increases output by almost 0.6 p.p. and inflation 0.9p.p. to the counterfactual scenario without intervention. However, its effects on output and inflation are milder in fiscal and monetary dominance regimes, where output increases by 0.3 and 0.2 p.p. and inflation by 0.6 and 0.5p.p., being considerably less persistent in the first case. This analysis provides some insights into the power of QE to expand the economy and how it differs among regimes. Furthermore, it highlights the fact that the fiscal implication of this policy entails substantial differences across policy scenarios.

7 Exit strategies from Quantitative easing programs

As stated by policymakers, financial analysts, and academics, there is high uncertainty regarding the impact of implementing Quantitative Easing programs and, even more, the unwinding of the economic stimulus introduced through these measures. The main objective of this paper is to contribute to understanding the macroeconomic effects of different strategies regarding the size of the central bank balance sheet. In this section, I simulate the economy to generate a crisis that resembles the one in the US from the first quarter of 2020 when the COVID-19 pandemic became widespread worldwide. First, I show the model can generate a crisis with similar characteristics to the data: a substantial fall in output and short-term interest rate until it reaches the zero lower bound, together with a rise in the debt-to-GDP ratio and a fall in the inflation rate. In this context, I simulate a Quantitative Easing program that increases the ratio of the central bank balance sheet over output by 10p.p. and compare the macroeconomic dynamics with and without this program. Then, I study three different strategies for managing the central bank balance sheet size: 1) maintaining the enlarged size after the crisis (*tapering*), 2) decreasing the balance sheet size: a) by letting the bonds that mature, run off the balance sheet (*Quantitative Tightening (QT)*), and b) at a faster speed by selling bonds (*Aggressive QT*).

Tapering is defined as a situation where the stock of long-term bonds at the central bank ($b_t^{L,CB}$) remains constant, implying $b_t^{L,CB} = b_{t-1}^{L,CB}$. With that objective, the central bank engages in new purchases of bonds to make up for maturing bonds. The size of the central bank balance sheet over output ratio is, however, endogenous since it is affected by the price of long-term bonds (Q_t^L) and output y_t, which are not under the control of the central bank.

Quantitative tightening is a strategy where the central bank does not repurchase the bonds that mature every period, letting them run off the balance sheet. The stock of bonds at the central bank will then decrease at rate δ, the average maturity of long-term bonds, the unique kind of bonds the monetary authority purchases in the model. This implies the stock of bonds follows: $b_t^{L,CB} = (1-\delta)\, b_{t-1}^{L,CB}$.

Finally, the strategy called *Aggressive QT* consists of the central bank actively selling public bonds. It is any path of shocks that generates $b_t^{L,CB} < (1-\delta)\, b_{t-1}^{L,CB}$, implying that the stock of bonds at the central bank decreases at a faster rate than the maturity rate.

7.1 The crisis development and the QE program

I simulate the model in 50,000 samples of 40 periods under two scenarios, "Baseline" and "Quantitative Easing," with the following characteristics. In the baseline, the economy is at the approximation point at t=1, and in the monetary-led regime. During periods 2 to 4, the economy is hit by strong negative preference and TFP shocks. Since both shocks are persistent, they remain below their steady state value for the whole sample. From t=2 onward, the regime at place is stochastic, following transition matrix presented in section 3.8. QE, monetary policy, and fiscal policy shocks are random in this scenario. After the initial hit during periods 2 to 4, preference and TFP shocks follow random paths.

The quantitative easing scenario shares the same characteristics as the baseline, except that the path for QE shocks is not random. It is imposed to generate an increase in the annualized central bank balance sheet to output around 10p.p. in the first six periods. After period 6, the balance sheet remains constant (tapering strategy).

Figure 7 shows the mean of simulated variables for the first 20 periods for the economy without QE (continuous blue line) and with QE (dotted orange line). The negative preference and technology shocks generate a substantial fall in output growth that reaches its bottom of almost -12p.p. in period four. Besides, it does not fully recover for nine periods. The short-term interest rate starts falling immediately until it reaches the ZLB. The primary fiscal surplus falls by almost 10p.p. in the baseline scenario.[24]

The main features of the crisis with quantitative easing are the following. First, there is a milder fall in output, which falls around 2p.p. less than without the program. Second, there is a faster recovery within less than a year. QE also has expansionary effects in terms of inflation. Prices fall less than without the intervention of the central bank. Inflation reaches a peak of 8% in period six, the same period at which the balance sheet reaches its maximum value of 20.8% of GDP. Without this program, inflation increases less during the recovery and reaches a peak of 6% three periods later.

In both cases, real debt increases quickly when the crisis starts, increasing around 20p.p. of GDP. However, its real value decreases fast following the output and price recovery. The fall in real debt is more significant under the QE program for three reasons: first, central bank purchases increase

[24]This exercise has the objective to analyze the effects of the quantitative easing program. This baseline exercise excludes the increase in fiscal transfers that took place during that period of turmoil. In the model, it can be easily generated through a fiscal shock in g_t, generating more significant primary fiscal deficits.

central bank profits transferred to the treasury; second, the central bank intervention decreases the long-run yield, and thus interest payments on debt are lower; and third, the faster recovery triggers a fall in government spending driven by automatic stabilizers so that the primary fiscal deficit is lower. These three factors allow the government to issue less debt during the crisis than in a counterfactual without the QE program.

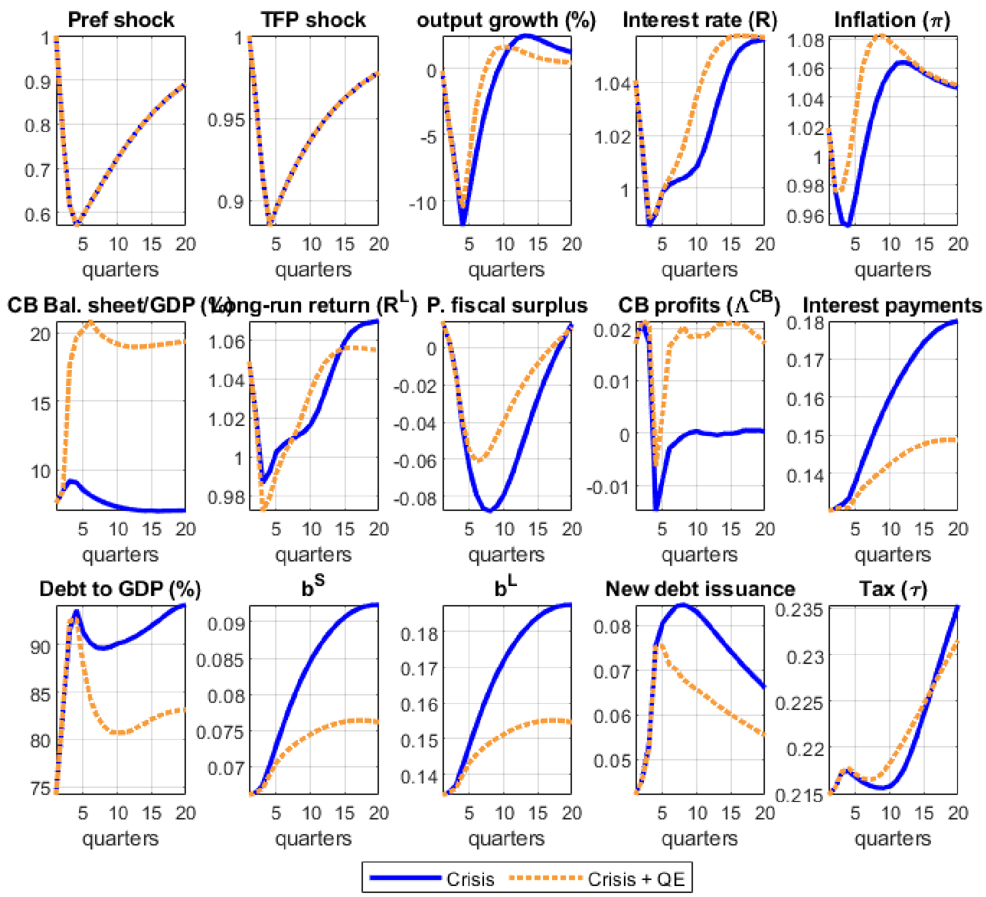

Figure 7: Simulated crisis

Note: Average from 50,000 samples. The continuous blue line is the scenario without the QE program. The Orange dotted line is the scenario with a QE program that increases the annualized central bank balance sheet to output by around 10p.p. Output growth, balance sheet, and Debt to GDP are in percentages. Interest rate (R), long-run return (R^L), inflation are annualized gross rates. Debt-to-GDP is annualized.

Finally, figure 8 shows, per period, the percentage of samples in which the economy is at the zero lower bound regime. Notice it is zero in periods one (initial condition) and two. The reason is that the endogenous probability of moving to the zero lower bound regime at $t+1$ depends on the interest rate at t. From period four onward, the economy is at the ZLB with a high probability. The frequency of this regime is considerably lower under the scenario with the QE program, and it is almost nil from period twelve.

To summarize, unconventional monetary policy intervention reduces the severity of the crisis and implies a faster recovery in terms of output. Additionally, the debt stock is lower while inflation is higher.

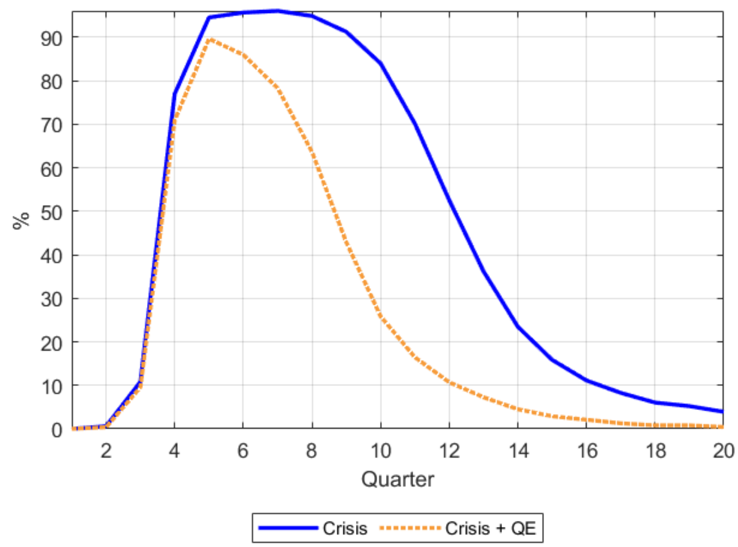

Figure 8: percentage of simulated samples at the ZLB regime, per period, from 50.000 samples. The continuous blue line is the scenario without the QE program. The Orange dotted line is the scenario with a QE program.

7.2 Central bank balance sheet exit strategies

This section compares the path for endogenous variables under three scenarios after the initial crisis. The continuous green line is the scenario with Quantitative Tightening (QT) from period 12 onward. Light-blue dashed line is the scenario with sales of bonds from period 12 onward[25]. The orange dotted line corresponds to tapering, identical to the one in figure 7.

The figure shows mean values for each variable across samples. This implies an average behavior where the regime is stochastic, i.e., which could leave the ZLB regime towards a fiscally-led regime or a monetary-led regime following the ergodic probabilities of matrix presented in section 3.8.

[25]For this scenario, I assume a QE shock equal to -0.2 for every t from t=12.

For clarity of exposition, I show the variables from period t=6. The unwinding of the balance sheet is assumed to start almost two years after the crisis, when most of the simulated samples are endogenously out of the ZLB (as shown in figure 4).

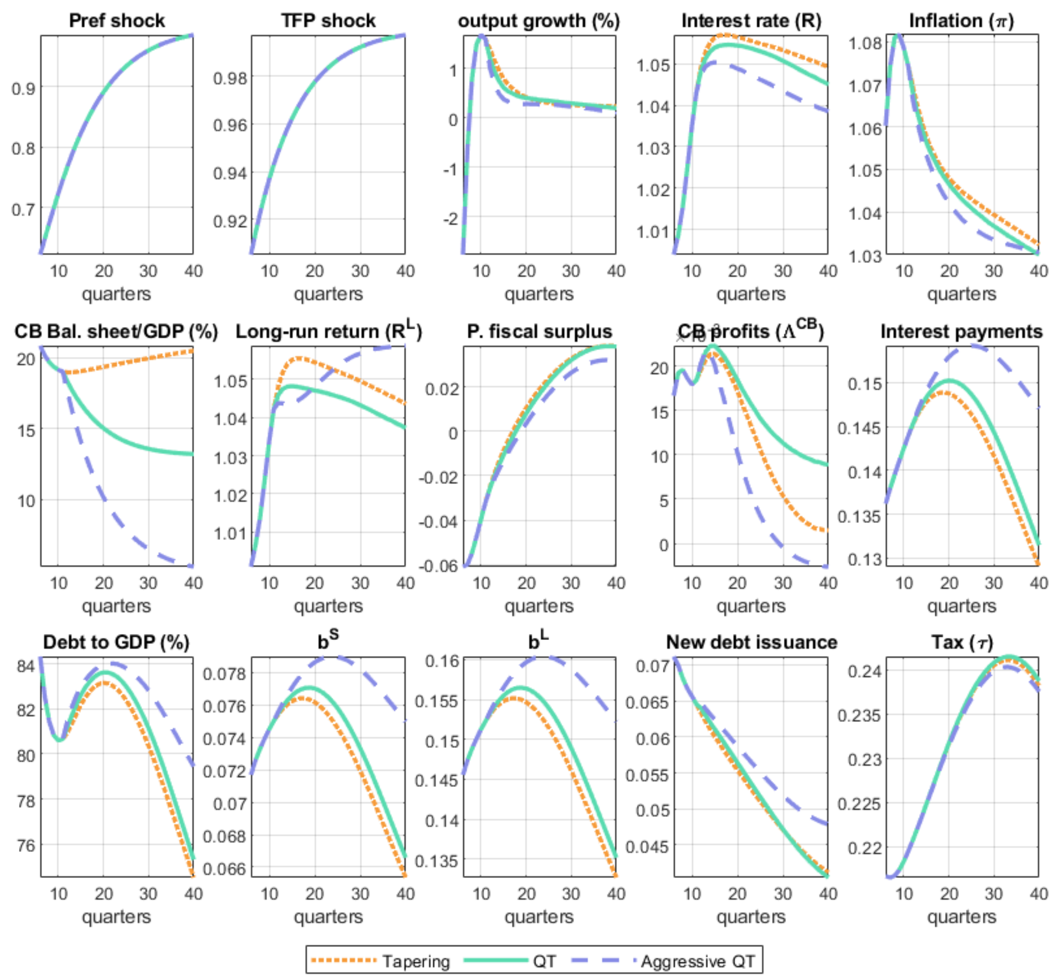

Figure 9: Crisis and exit strategies from QE.

Note: Average from 50.000 samples, since period t=6. The Orange dotted line is the tapering scenario, the same as the one in figure 7. The continuous green line is the scenario with Quantitative Tightening (QT) from period 12 onward. Light-blue dashed line is the scenario with Aggressive QT or sales of bonds from period 12 onward. Output growth, balance sheet, and Debt to GDP are in percentages. Interest rate (R), long-run return (R^L), inflation, debt/GDP are annualized.

When the central bank unwinds its balance sheet, it decreases the total demand for long-term bonds, pushing their price down, and generating a rise in the long-term yield. This price effect causes incentives in households to rebalance its portfolio away from deposits and toward long-term public bonds. At the same time, since households were already investors in these assets, they perceive a negative wealth effect from the revaluation of their portfolio, decreasing consumption and aggregate demand in the economy. This effect dominates the substitution effect that generates incentives to save more in the context of rising interest rates.

Firms respond to this fall in aggregate demand, mainly through a decrease in prices and real wages. Since TFP is still recovering from the crisis, this simple model with linear production prevents a severe recession, and the adjustment takes place mainly through prices. In this context, unwinding the central bank balance sheet generates a faster inflation stabilization, allowing the central bank to stop increasing the short-term nominal interest rate. The disinflationary forces of reducing the central bank balance sheet are more substantial as the unwinding speed gets faster. Under an aggressive QT, after four years of applying this strategy (period t=27) and in the absence of further shocks, the inflation rate is 3.5%, while it remains at 4% under tapering. Moreover, this is accomplished with a short-term interest rate of 1p.p. lower than in the tapering scenario. In a longer horizon (40 periods from the beginning of the simulation), we can see that the inflation rate stabilizes at a higher level when the size of the balance sheet remains constant after the expansion during the crisis. In other words, more liquidity permanently circulating in the economy increases the long-term inflation rate.

On the fiscal side, we observe that the stock of debt increases with the unwinding of the balance sheet, disregarding which measure we analyze (i.e., real debt, new issuance or b^S and b^L). There are three reasons. First, the negative effects on output trigger government spending through automatic stabilizers, decreasing the fiscal surplus even as taxes increase. Second, interest payments increase due to higher interest rates. Third, central bank remittances to the treasury decrease in the scenario of sales of bonds. Notice that when the short-term interest rate increases, the central bank starts paying interest rates on reserves, decreasing its profits. With the unwinding, bank reserves which constitute the liabilities in its balance sheet, decline, reducing this cost. However, at the same time, it generates a fall in the return it receives for its holdings of long-term bonds. Under QT, the first effect dominates, and central bank profits increase compared to the tapering scenario. The opposite happens in an aggressive QT, where the unwinding is faster.

In conclusion, a sale of bonds from the central bank is more effective in reducing the inflation rate to the target, requiring smaller increases in the short-term interest rate. However, it has the downside of a slower deleveraging of the economy. As I show in the next section, these conclusions are not independent of the policy regime at the time of the unwinding.

7.3 Unwinding the balance sheet in a fiscally-led regime

In this section, I restrict the analysis to the samples that exit the zero lower bound toward a fiscally-led regime and stay there for at least one year (4 quarters). I compare it with the selected samples where the exit from the ZLB is toward the monetary regime. Since both fiscally and monetary-led regimes are substantially persistent, the probability of staying there for a good proportion of the sample is high. The exit of the crisis regime is stochastic and could happen at any period. In the figure 10, I present the dynamics corresponding to these subsamples.

Exiting the crisis towards a fiscally-led regime brings a higher inflation rate that peaks at 12% in period nine and an expansionary period where output growth is above trend. As a result, interest rates are higher, even under lower reactions to inflation and output deviations. Higher inflation rates help to quickly reduce the stock of real debt, which falls 20p.p. of GDP in 7 quarters.

The most remarkable difference between this scenario and the one analyzed in the previous section is that unwinding the central bank balance sheet brings no benefits in terms of inflation stabilization. The negative demand effect driven by the reduction in central bank purchases is not enough to counteract the stimulative impact of negative interest rates and fiscal stimulus. Furthermore, the downside of these strategies (slower deleveraging of the economy and higher long-term yields) remain present under both regimes.

In conclusion, in a regime where the fiscal authority is not committed to stabilizing the government debt, and does not allow the central bank to ensure price stability, unwinding the central bank balance sheet does not generate clear economic advantages.

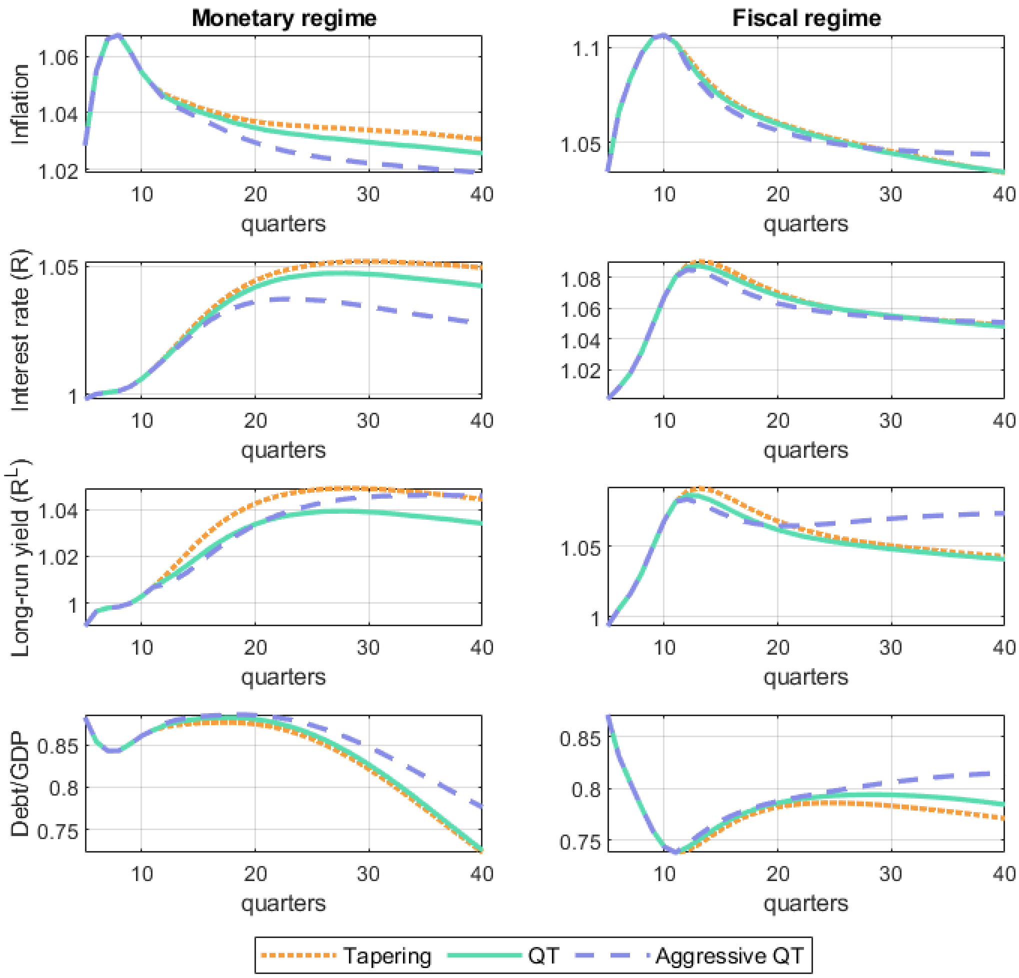

Figure 10: Crisis and exit strategies from QE, conditional on a regime.

Note: Simulation of 50,000 samples, since period t=6. The figure restricts the analysis to samples that exit the zero lower bound toward a monetary-led regime (left) or fiscally-led regime (right) and stay there for at least one year (4 quarters). The Orange dotted line is the tapering scenario, the same as the one in figure 7. The continuous green line is the scenario with Quantitative Tightening (QT) from period 12 onward. Light-blue dashed line is the scenario with Aggressive QT or sales of bonds from period 12 onward. Debt to GDP is in percentages. Interest rate (R), long-run return (R^L), inflation, debt/GDP are annualized.

8 Concluding Remarks

I study different exit strategies for reducing the central bank balance sheet in a model that generates fiscal-monetary policy trade-offs.

The impact of central bank balance sheets policies (either QE or QT) depends on the fiscal-monetary policy mix. First, QE reduces the need for new debt issuance. Second, as a counterpart of the central bank's balance sheet expansions, liquidity increases substantially, both in the hand of commercial banks (reserves) and non-bank private agents (deposits). The extent to which the increase in liquidity affect output and inflation rate depends on the fiscal-monetary policy mix. QE is more expansive at the Zero Lower Bound and under the fiscally led regime when the inflationary impact is also more significant.

How the central bank balance sheet's size is reduced matters for inflation, output, and debt dynamics. In an average simulation, when the monetary authority starts shrinking its holdings of long-term government bonds, either without repurchasing the ones that mature (QT) or actively selling its position in the secondary market (aggressive QT), it decreases inflation at the cost of an increase in the ratio of debt/GDP. These effects increase when the exit strategy is more aggressive.

When the unwinding occurs in a fiscal-led regime, reducing the balance sheet's size does not help bring the inflation back to target. This is because the negative demand effect driven by the reduction in central bank purchases is not enough to counteract the stimulative impact of negative interest rates and fiscal stimulus. Furthermore, the downside of these strategies (less deleveraging of the economy and higher term spreads) remains present under both the fiscal and the monetary led regime. This implies that, with unconventional policies, coordination between fiscal and monetary authorities is necessary to stabilize inflation.

9 Appendix

9.1 Extra plots for US case

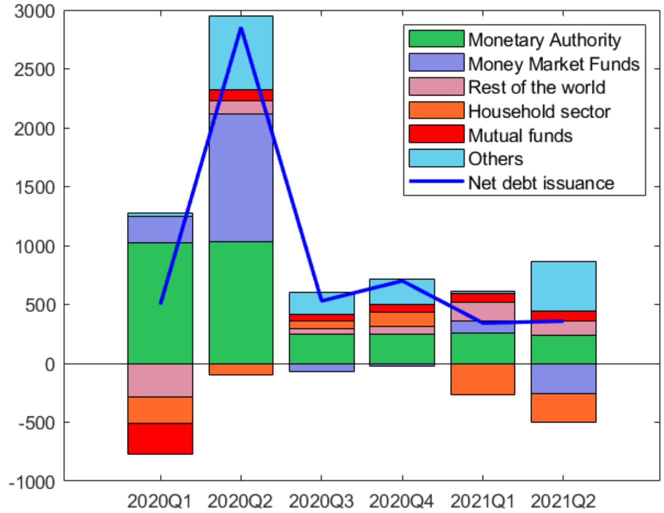

Figure 11: Change in Treasuries' holdings

Source: US Financial Accounts. Data in billions of dollars. Contain revaluation effects.

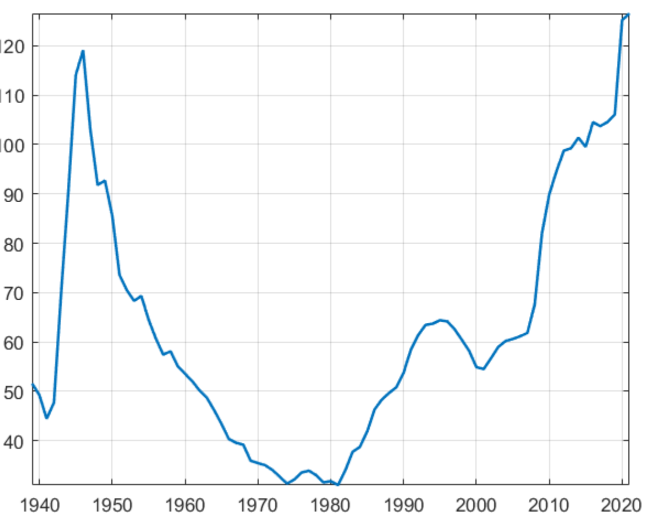

Figure 12: Public debt to GDP in US: historical perspective

Source: FRED. Annual Gross Federal Debt as a Percent of GDP.

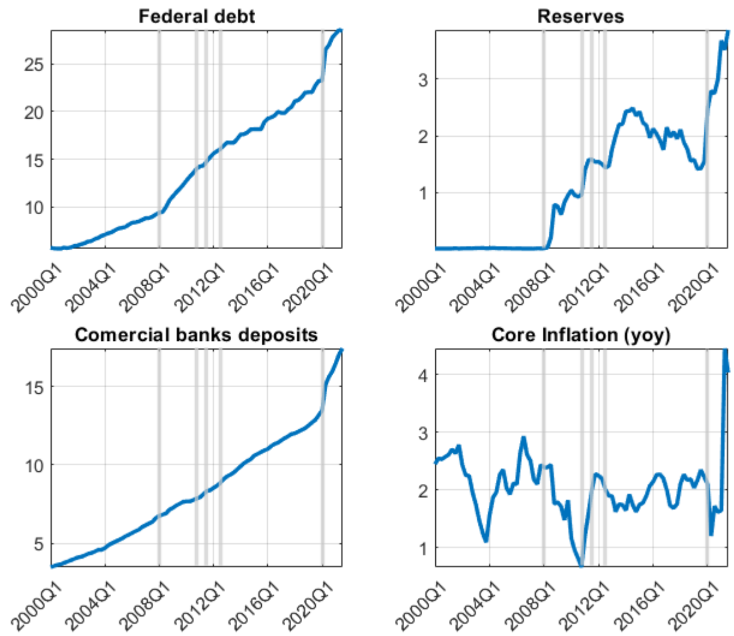

Figure 13: Macroeconomic variables: public debt, liquidity, inflation. Great recession and COVID-19 crisis.

US Federal Debt, Reserves and Deposits, in trillions of dollars. Core inflation in %. Source debt, deposits and inflation data: FRED. Source reserves: US financial accounts, release December 2021.

9.2 Model: Financial intermediary optimization problem

The optimization problem of a representative financial intermediary can be written in sequential form as follows:

$$V^I\left(W_t^I\right) = \max_{A_t, D_t^I, F_t^I, B_t^{S,I}} \tau^I W_t^I - A_t + \mathbb{E}_t\left[\mathcal{M}_{t,t+1} V^I\left(W_{t+1}^I\right)\right]$$

$$\text{s.t. } (1-\tau^I)W_t^I + A_t - \Phi_A(A_t) + Q_t^D D_t^I = Q_t^S B_t^{S,I}$$

$$W_t^I = B_{t-1}^{S,I} - D_{t-1}^I$$

$$D_t^I \leq \zeta B_t^{S,I}$$

Define η_t as the Balance sheet multiplier and μ_t as the Leverage constraint multiplier. The first order conditions are given by the following system:

$$A_t : -1 + \eta_t - \eta_t \chi \frac{A_t}{P_t} = 0$$
$$D_t^I \colon \eta_t Q_t^D - \mu_t - \mathbb{E}_t \mathcal{M}_{t,t+1} V_w^I \left(W_{t+1}^I\right) = 0$$
$$B_t^{S,I} : -\eta_t Q_t^D + \mu_t \zeta + \mathbb{E}_t \mathcal{M}_{t,t+1} V_w^I \left(W_{t+1}^I\right) = 0$$

And the envelope condition:

$$V_w^I \left(W_{t+1}^I\right) = \tau^I + \eta_t (1 - \tau^I)$$

Using the first order condition with respect to A_t to substitute out the multiplier η_t, we obtain the system of equations that characterize the financial intermediary's optimization problem, together with 7, 8, 9, **??**:

$$Q_t^D = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \mu_t \left(1 - \chi a_t\right) \tag{22}$$

$$Q_t^S = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \zeta \mu_t \left(1 - \chi a_t\right) \tag{23}$$

Where $\tilde{\mathcal{M}}_{t,t+1}$ is the stochastic discount factor for financial intermediaries, defined as:

$$\tilde{\mathcal{M}}_{t,t+1} \equiv \mathcal{M}_{t,t+1} \left(1 - \chi \frac{A_t}{P_t}\right) \left(\tau^I + \frac{1 - \tau^I}{1 - \chi \frac{A_{t+1}}{P_{t+1}}}\right)$$

9.3 Equilibrium conditions

In this section I present the system of equilibrium conditions with functional forms and in real terms.

Definitions: $d_t = \frac{D_t}{P_t}$, $b_t^{j,i} = \frac{b_t^{j,i}}{P_t}$, $w_t = \frac{W_t}{P_t}$, $div_t = \frac{Div_t}{P_t}$, $\pi_t^f = \frac{\Pi_t^f}{P_t}$, $a_t = \frac{A_t}{P_t}$, $mc_t = \frac{MC_t}{P_t}$, $w_t^I = \frac{W_t^I}{P_t}$, $\pi_t = \frac{P_t}{P_{t-1}}$, for $j \in \{L, S\}$, $i \in \{H, CB, FI\}$.

9.3.1 Households

$$c_t + Q_t^D d_t^H + b_t^{L,H} Q_t^L = w_t n_t - \tau_t + \frac{d_{t-1}^H}{\pi_t} + \frac{b_{t-1}^{L,H}}{\pi_t} \left[\kappa + (1-\delta) Q_t^L\right] + div_t + \pi_t^f + \frac{\chi}{2} a_t^2 \tag{1}$$

$$\frac{\gamma n_t^\eta}{\left[c_t^{1-\varphi}\left(d_t^H\right)^\varphi\right]^{-\sigma}(1-\varphi)c_t^{-\varphi}(d_t^H)^\varphi} = w_t \tag{2}$$

$$Q_t^D = \mathbb{E}_t \mathcal{M}_{t,t+1} + \frac{\varphi c_t}{(1-\varphi)d_t^H} \tag{3}$$

$$Q_t^L + \phi^L \frac{b_t^{L,H}}{(b^{L,H})^2} = \mathbb{E}_t \mathcal{M}_{t,t+1}\left[\kappa + (1-\delta)Q_{t+1}^L\right] \tag{4}$$

$$\mathcal{M}_{t,t+1} = \frac{\beta\lambda_{t+1}}{\lambda_t} = \beta\mathbb{E}_t \frac{\left[c_{t+1}^{1-\varphi}\left(d_{t+1}^H\right)^\varphi\right]^{-\sigma} c_{t+1}^{-\varphi}(d_{t+1}^H)^\varphi}{\left[c_t^{1-\varphi}\left(d_t^H\right)^\varphi\right]^{-\sigma} c_t^{-\varphi}(d_t^H)^\varphi} \frac{1}{\pi_{t+1}} \tag{5}$$

9.3.2 Firms

$$y_t = z_t n_t \tag{6}$$

$$\pi_t^f = y_t - w_t n_t - \frac{\phi^P}{2}\left(\pi_t - 1\right)^2 y_t \tag{7}$$

$$1 - \varepsilon + \varepsilon mc_t = \phi_P\left(\pi_t - \pi^*\right)\pi_t - \phi_P \mathbb{E}_t\left[\mathcal{M}_{t,t+1}\frac{y_{t+1}}{y_t}\pi_{t+1}^2\left(\pi_{t+1} - \pi^*\right)\right] \tag{8}$$

$$w_t = mc_t z_t \tag{9}$$

9.3.3 Financial intermediaries

$$div_t = \tau^I w_t^I - a_t \tag{10}$$

$$(1-\tau^I)w_t^I + a_t - \frac{\chi}{2}a_t^2 + Q_t^D d_t^I = Q_t^S b_t^{S,I} \tag{11}$$

$$w_t^I = \frac{b_{t-1}^{S,I}}{\pi_t} - \frac{d_{t-1}^I}{\pi_t} \tag{12}$$

$$d_t^I \leq \zeta b_t^{S,I} \tag{13}$$

$$Q_t^D = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \mu_t\left(1 - \chi a_t\right) \tag{14}$$

$$Q_t^S = \mathbb{E}_t \tilde{\mathcal{M}}_{t,t+1} + \zeta\mu_t\left(1 - \chi a_t\right) \tag{15}$$

$$\tilde{\mathcal{M}}_{t,t+1} = \mathcal{M}_{t,t+1}\left(1 - \chi a_t\right)\left(\tau^I + \frac{1-\tau^I}{1-\chi a_{t+1}}\right) \tag{16}$$

9.3.4 Government

$$\frac{1}{R_t} = Q_t^S \tag{17}$$

$$Q_t^S b_t^{S,CB} + Q_t^L b_t^{L,CB} = 0 \tag{18}$$

$$b_t = Q_t^S b_t^S + Q_t^L b_t^L \tag{19}$$

$$b_t^S = (1-\bar{\mu})/\bar{\mu} b_t^L \tag{20}$$

$$g_t = \theta(y^* - y_t) + (1-\rho_g)\bar{g} + \rho_g g_{t-1} + \sigma_g \varepsilon_t^g,\, \varepsilon_t^g \sim N(0,1) \tag{21}$$

9.3.5 Market clearing conditions

$$c_t + g_t + \frac{\phi_P}{2}\left(\pi_t - \pi^*\right)^2 y_t = y_t \tag{22}$$

$$d_t^H = d_t^I \tag{23}$$

$$b_t^S = b_t^{S,I} + b_t^{S,CB} \tag{24}$$

$$b_t^L = b_t^{L,H} + b_t^{L,CB} \tag{25}$$

9.3.6 Policy rules

$$\tau_t - \tau^* = \rho_\tau\left(\xi_t\right)\left(\tau_{t-1} - \tau^*\right) + \left(1 - \rho_\tau\left(\xi_t\right)\right)\gamma\left(\xi_t\right)\left(b_{t-1} - b^*\right) \tag{16}$$

$$\frac{R_t}{R\left(\xi_t\right)} = \left(\frac{R_{t-1}}{R\left(\xi_t\right)}\right)^{\alpha_R(\xi_t)} \left[\left(\frac{\pi_t}{\pi^*}\right)^{\alpha_\pi(\xi_t)} \left(\frac{y_t}{y^*}\right)^{\alpha_y(\xi_t)}\right]^{1-\alpha_R(\xi_t)} e^{\sigma_M(\xi_t)\epsilon_t^M} \tag{27}$$

$$b_t^{L,CB} = (1-\rho^{QE}) b_*^{L,CB} + \rho^{QE} b_{t-1}^{L,CB} + \sigma^{QE}\epsilon_t^{QE} \tag{28}$$

Law of motion for exogenous processes: z_t, ν_t.

Transition matrix for Markov-switching shock ξ_t.

9.3.7 Definition of auxiliary variables used in figures and tables

Return on long-term bond:

$$R_{t,t+1}^L = \mathbb{E}_t \frac{\kappa + (1-\delta)Q_t^L}{Q_{t+1}^L}$$

Convenience yield:

$$cy_t = R_t - \frac{1}{\mathcal{M}_{t,t+1}}$$

Annual debt to GDP ratio:

$$\frac{b_t}{4y_t}$$

Primary fiscal surplus:

$$s_t = \tau_t - g_t$$

Total interest rate payments:

$$(R_{t-1} - 1)\frac{b^S_{t-1}}{\pi_t} + (\kappa - \delta)\frac{b^L_{t-1}}{\pi_t}$$

Private interest rate payments:

$$(R_{t-1} - 1)\frac{b^{S,FI}_{t-1}}{\pi_t} + (\kappa - \delta)\frac{b^{L,H}_{t-1}}{\pi_t}$$

Total debt service:

$$\frac{b^S_{t-1}}{\pi_t} + \kappa\frac{b^L_{t-1}}{\pi_t}$$

9.4 Steady state and approximation point

At the steady state, shocks are equal to zero: $\epsilon^{\nu}_t = 0$, $\epsilon^z_t = 0$, $\epsilon^g_t = 0$, $\epsilon^m_t = 0$, $\epsilon^{QE}_t = 0$.

Then: $z^{ss} = 1$, $\nu^{ss} = 1$, $g^{ss} = \bar{g}$, $b^{L,CB,ss} = b^{L,CB}_*$.

There is one endogenous variable which steady state value differs among regimes. For monetary ($\xi^C_t = 0$ and $\xi^P_t = M$) or fiscal ($\xi^C_t = 0$ and $\xi^P_t = F$) dominance regimes, we have: $R_t = R^*$ in absence of shocks. For the Zero lower bound regime ($\xi^C_t = 1$), $R_t = 1.0005$. Define p^M, p^F, p^C as the ergodic probability of monetary dominance, fiscal dominance or crisis regime, respectively. Where: $p^M + p^F + p^C = 0$. The short-term nominal interest rate at the approximation point is obtained as follows:

$$R^{ss} = \left(p^M + p^F\right) R^* + \left(1 - p^M - p^F\right) 1.0005$$

9.5 Additional results

9.5.1 Determinacy regions for fiscal and monetary policy rules

The following figure shows combinations for policy parameters γ and α_π that give rise to a unique equilibrium (determinacy, yellow areas), given the calibration for the rest of the parameters, in the monetary-led regime. The blue areas represent parameter combinations that generate either no equilibrium, or multiple equilibria.

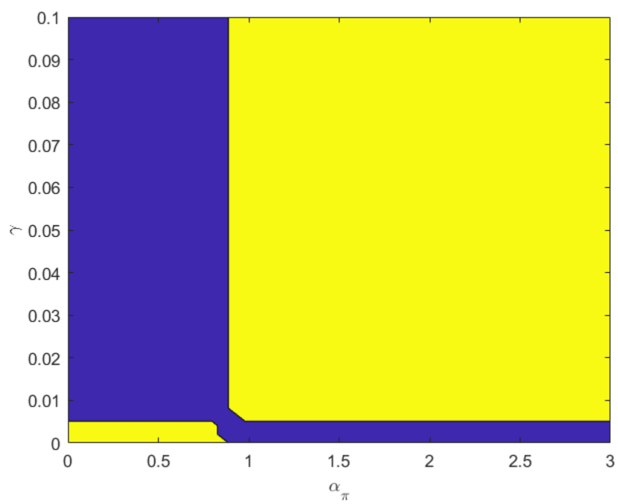

Figure 14: Determinacy regions

Note: Yellow areas represent combinations of parameters α_π and γ that give rise to determinacy. Blue areas represent either multiple equilibria or no equilibrium.

9.5.2 Impulse response functions for additional shocks

This section presents figures showing the impact of the different shocks in the model, under different regimes. They show log deviations (in %) in a simulated path with a one standard deviation shock, to the counterfactual path without the shock.

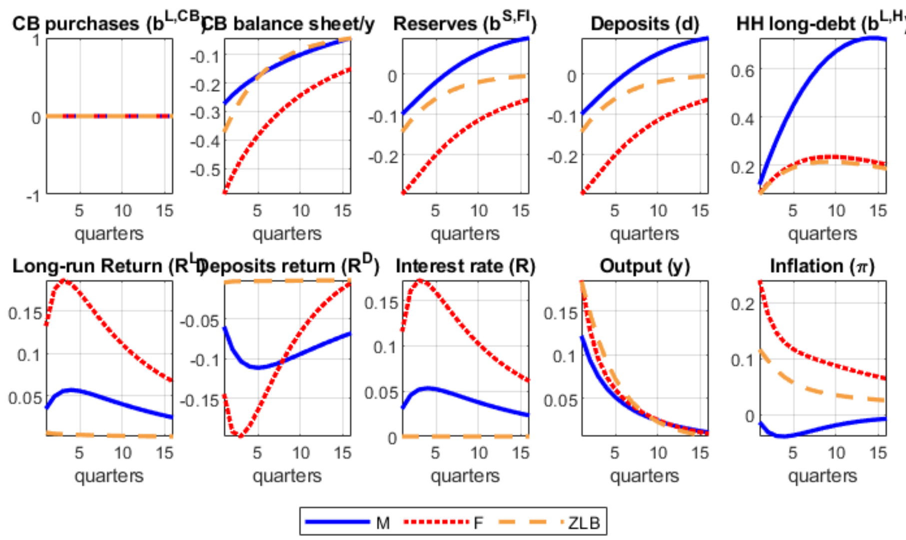

Figure 15: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the government spending ($\epsilon_t^g = 1$) to the counterfactual path without shock ($\epsilon_t^g = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

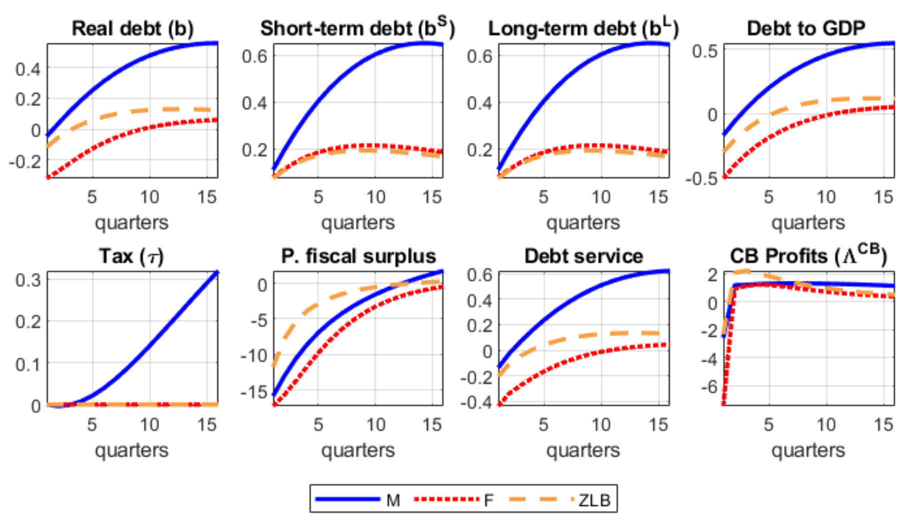

Figure 16: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the government spending ($\epsilon_t^g = 1$) to the counterfactual path without shock ($\epsilon_t^g = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

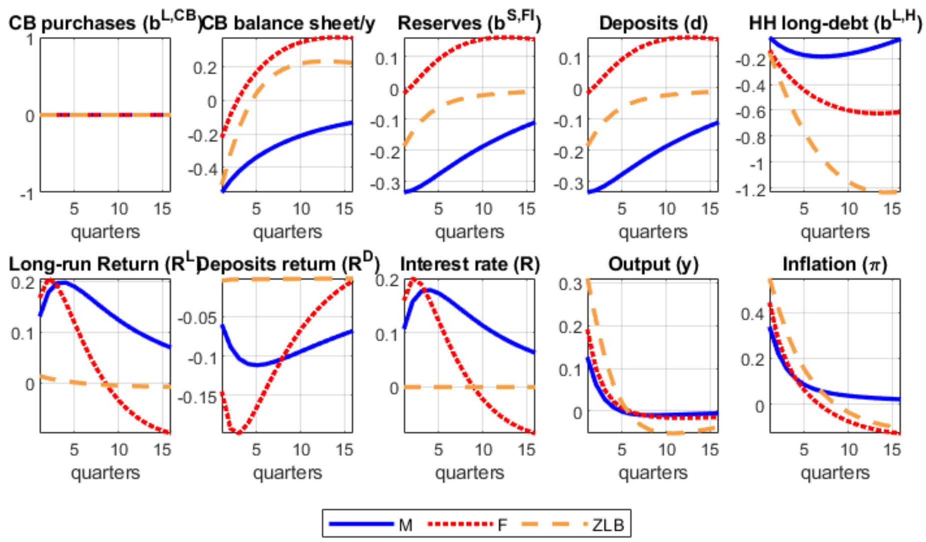

Figure 17: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the preferences ($\epsilon_t^\nu = 1$) to the counterfactual path without shock ($\epsilon_t^\nu = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

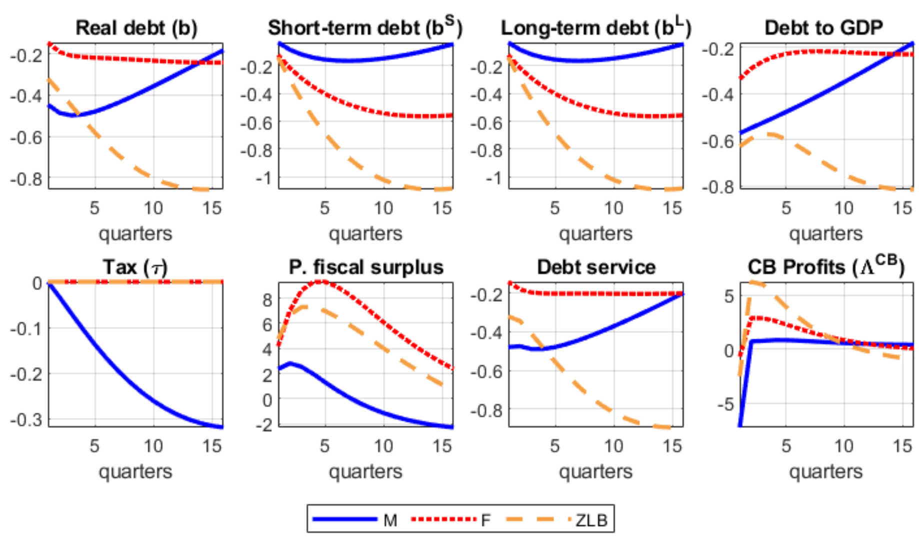

Figure 18: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation shock in the preferences ($\epsilon_t^\nu = 1$) to the counterfactual path without shock ($\epsilon_t^\nu = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

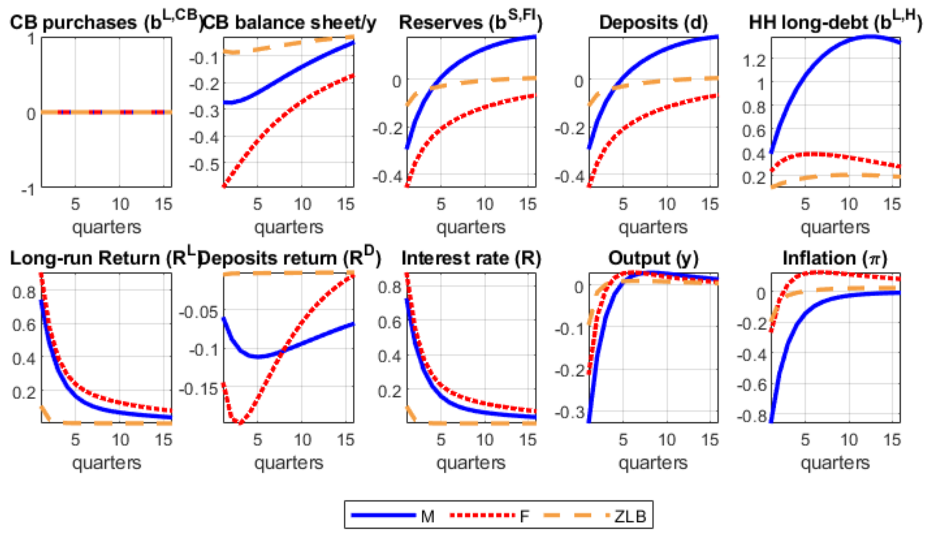

Figure 19: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation monetary shock ($\epsilon_t^m = 1$) to the counterfactual path without shock ($\epsilon_t^m = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

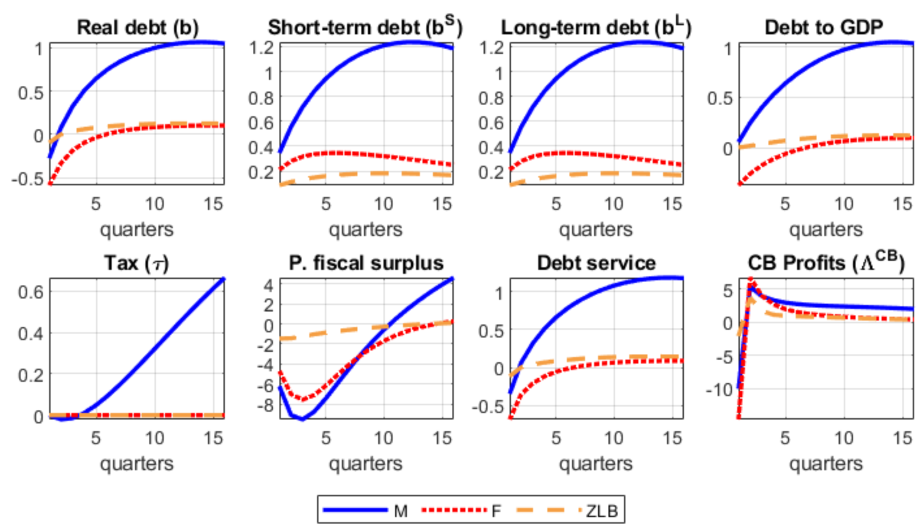

Figure 20: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation monetary shock ($\epsilon_t^m = 1$) to the counterfactual path without shock ($\epsilon_t^m = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

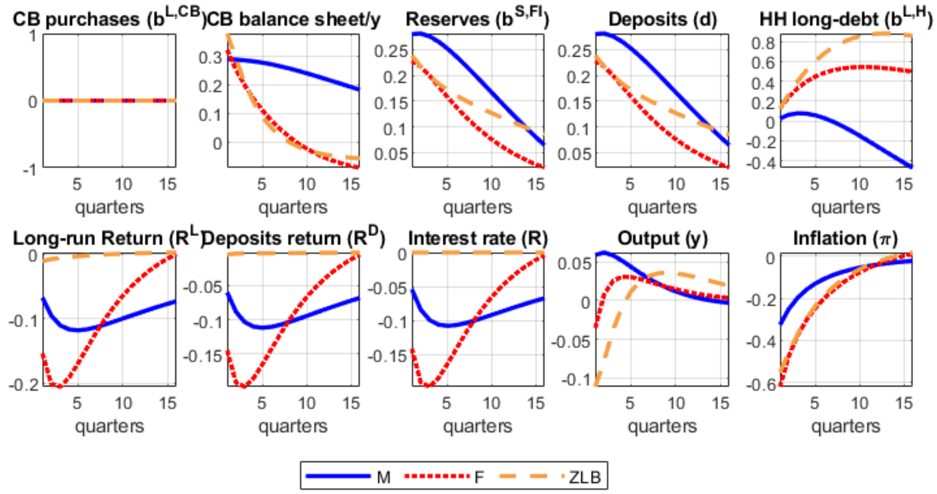

Figure 21: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation TFP shock ($\epsilon_t^z = 1$) to the counterfactual path without shock ($\epsilon_t^z = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

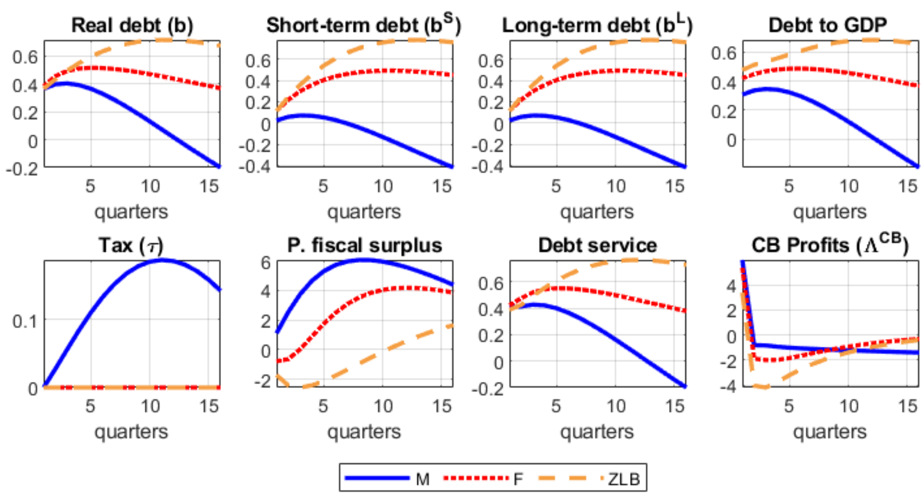

Figure 22: Impact of a Quantitative Easing shock conditional on a regime

Note: log deviations (in %) in a simulated path with a one standard deviation TFP shock ($\epsilon_t^z = 1$) to the counterfactual path without shock ($\epsilon_t^z = 0$). Path conditional on the monetary-led regime (continue blue line), fiscally-led regime (dotted red line), and zero lower bound regime (dashed yellow line) for 16 periods.

9.6 Data sources

The following table presents data sources for plots in section 2 and calibration.

Variable	Source	Table
Deposits in depositary institutions	FRED	
Monetary aggregate M1	FRED	
CPI	FRED	
US GDP Implicit Price Deflator, Index 2015=100	FRED	
Federal reserve Assets	US Financial Accounts	L109
Federal Reserve Total treasuries	US Financial Accounts	L110
Federal Reserve Treasury bills	US Financial Accounts	L111
Federal Reserve Other treasuries	US Financial Accounts	L112
Federal Reserve Total liabilities	US Financial Accounts	L113
Federal Reserve Reserves	US Financial Accounts	L114
Checkable Accounts in Federal Reserve	US Financial Accounts	L115
Total public debt	FRED	
Effective federal funds rate	FRED	
10-year Yield	FRED	
1-year Yield	FRED	
US GDP	BEA	NIPA
Private consumption	BEA	NIPA
Government spending	BEA	NIPA
US Population	FRED	

Table 7: Data sources

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